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Color schemes for electric circuit maps

Mehdi Jamshidipour
San Jose State University

COLOR SCHEMES FOR ELECTRIC CIRCUIT MAPS

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Mehdi Jamshidipour

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Light energy and color may be out there, but once light crosses the threshold of the eye, the brain takes over and does astonishing things with it. And at times, as in dreams, the brain may create "pictures" of its own without outside stimulation. (Birren, 1976)

APPROVED FOR THE DEPARTMENT OF GEOGRAPHY

Dr. Richard A. Taketa
Associate Professor of Geography and Graduate Advisor

Dr. David E. Schwarz
Professor Emeritus of Geography

David Matson
GIS Manager City of Palo Alto

APPROVED FOR THE UNIVERSITY

ABSTRACT

COLOR SCHEMES FOR ELECTRIC CIRCUIT MAPS

by Mehdi Jamshidipour

The objective of this paper is to address the superiority of color over black and white on an electric circuit map. For this paper, the circuit map of the City of Palo Alto, which owns and operates its utilities, has been selected. The internal structure of the circuit map reveals that its components can be divided into five major categories:

1. Base map
2. Shaded polygons
3. Text
4. Circuits
5. All other features

By understanding the principles of color, and by using existing color guidelines available from other areas of cartography and mapping, an attempt was made to assign a color (or a set of colors) for each category. These colors were then used and tested on a pilot map against a black and white pilot map. Finally, by using appropriate statistical methods, the hypothesis of superiority of color over black and white on an electric circuit map was examined and confirmed by using Utilities staff as a test sample.

ACKNOWLEDGEMENTS

I would like to extend my appreciation to Professor Taketa for his continuous guidance on this research, and his assistance with the references, evaluation process, and statistical analysis. I would also like to thank Professor Schwarz for reviewing the thesis manuscript, and accepting to be a committee member with a very short notice, despite his busy schedule, and Professor Freeman for having assisted me during the early stages of this paper. I am grateful for Mr. David Matson's commitment to serve as a committee member and for validating the material that relates to the City of Palo Alto GIS. I am also thankful to Maureen Kelley who assisted me with assembling the protocol for the Human Subjects Institutional Review Board.

I am thankful to my colleagues James Bujtor, P.E., Electrical Project Engineer, and Taha Fattah, Senior Market Analyst, for checking the accuracy of statements pertaining to the City of Palo Alto's Electric Utilities and to Dr. Kelly Jean Fergusson, P.E., GIS Consultant to the City of Palo Alto, for having reviewed this paper. I wish to thank all of my friends and colleagues for participating in the research, reading the paper, and providing me with feedback and comments.

Last but not least, I am thankful to the City of Palo Alto's Electric Engineering management, especially Tomm Marshall, P.E., and Patrick Valath, P.E., for supporting this research and allowing me to examine the hypothesis using Utilities staff as a test sample.

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CHAPTER 1

1.0 INTRODUCTION

The Geographic Information System[1] (GIS) and its accessories, which include color monitors, color scanners, color printers, and color plotters, is being used by the City of Palo Alto to replace existing manually drawn black and white flat maps. One set of flat maps being converted consists of the 12 primary electrical distribution circuit maps showing 55 feature classes, each with several sub-feature classes (a sample is depicted in Map 1). For example, a distribution power transformer is a feature class and a dual rated distribution power transformer is one of its sub-feature classes. Furthermore, 10 electric power substations serve the City of Palo Alto, which owns and maintains its utilities. Several primary circuits, or feeders, depart from each electric power substation. These feeders are classified as either 4 Kilo Volts (KV) feeders or 12KV feeders. The feeders serve the regions they pass through by way of underground or overhead transformers; the transformers reduce the primary voltage to a secondary voltage (ranging anywhere from 480 volts down to 120 volts) for the customers. The exception is large industrial customers, where a feeder directly serves these customers who own and maintain their own transformers.

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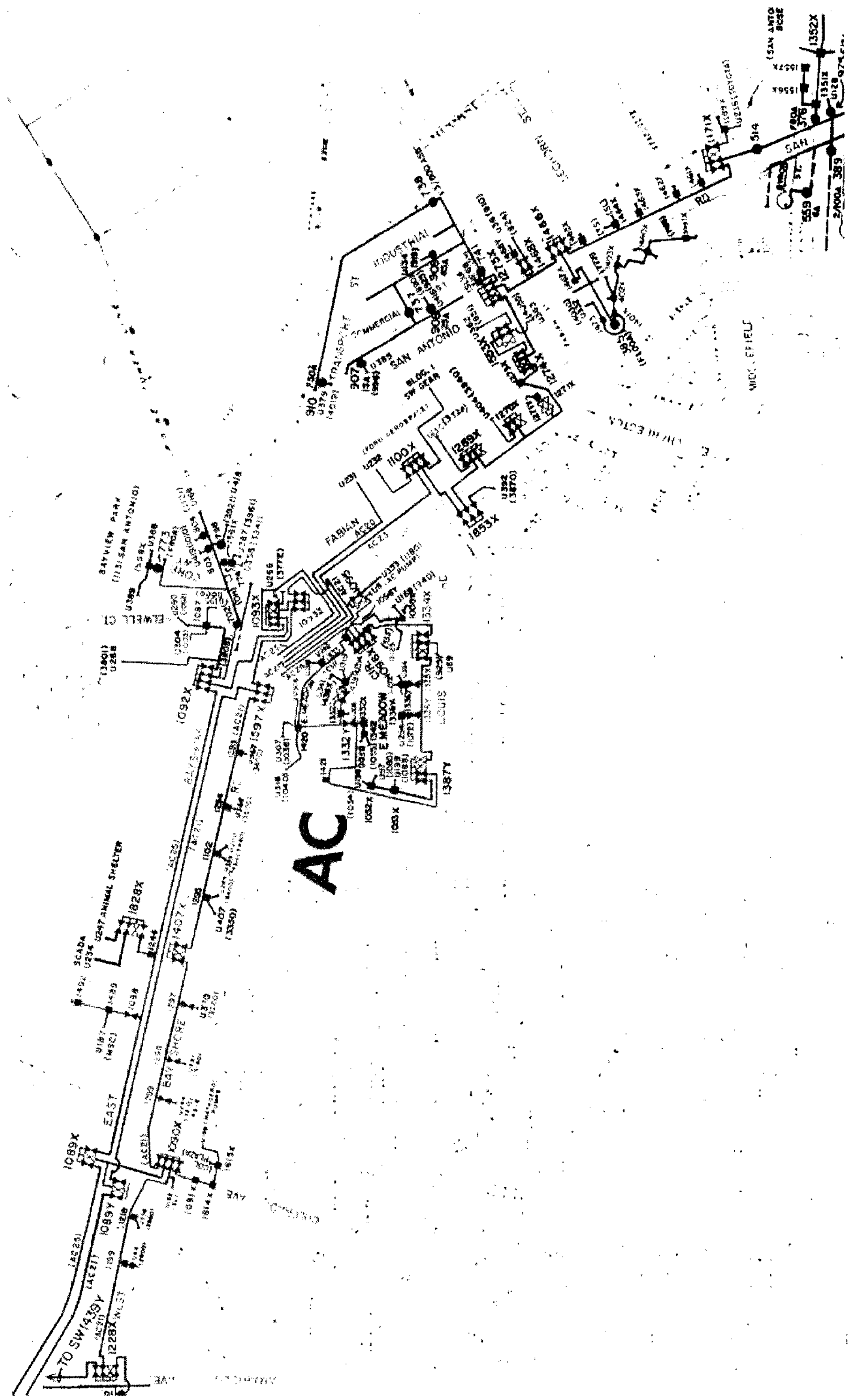
[1] A computer application to collect, store, manipulate, and analyze map information.

Map 1– One sample of the existing hand drawn circuit maps (flat maps)



The complexity of the circuit map, advances in technology, and high expectations of the utility staff from the GIS environment make necessary the use of color to represent the information on the circuit map. Map users prefer color maps to black and white maps. Color permits map reading to be more efficient and accurate (Brewer, MacEachren, Pickle, & Herman, 1997). Color affects the general perceptibility, such as legibility and visual acuity of the maps. Moods (psychological and emotional sensations stimulated in map users) can be created with colors (Dent, 1999). On the other hand, the complexity and seductiveness of color can overwhelm mapmakers; various maps in computer graphics demonstrations, business presentations, and daily newspapers expose a widespread lack of knowledge as to how color should be used in a map (Monmonier, 1991). Widespread lack of color knowledge can also lead to a poorly designed color map that is likely inferior to its black and white map version.

The goal of this research is to test for the superiority of a color circuit map over a black and white circuit map. This was done by applying basic concepts of light, color, and vision to select a color (or a set of colors) for the various features of the circuit map, plotting this selection on white bond paper, examining it against a black and white circuit map, and using Utilities staff of the City of Palo Alto as test subjects.

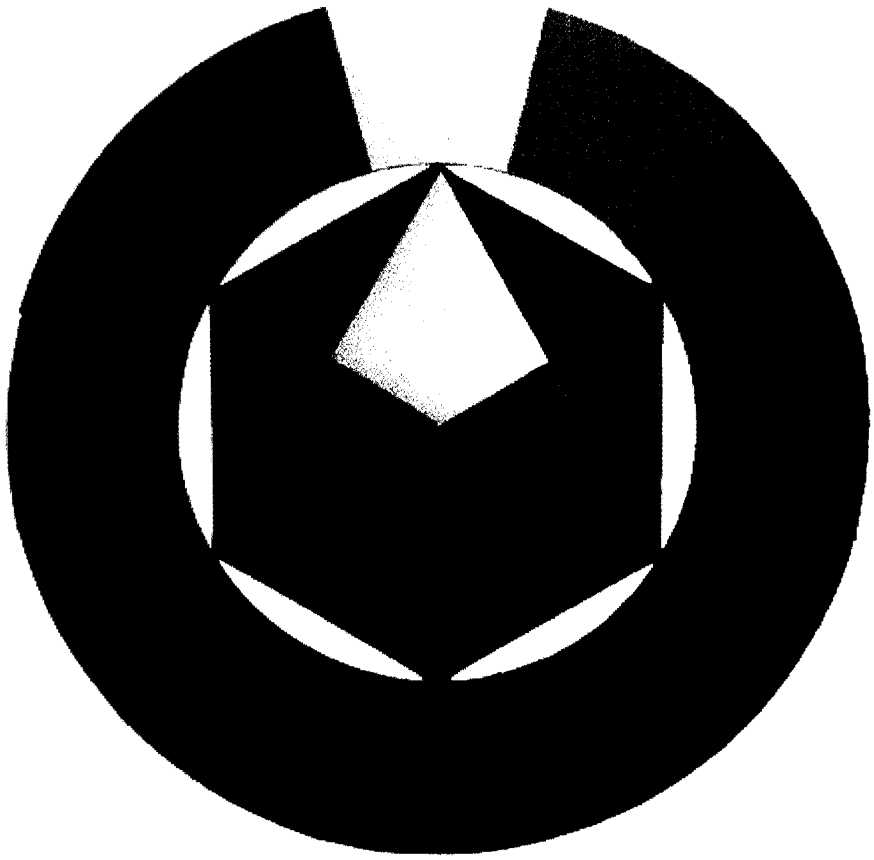
When hypothesizing about the superiority of color circuit maps over black and white circuit maps, the assumption is that colors (which include black and gray) are chosen carefully, based on knowledge and experience of color concepts. Some of these concepts, which are related to circuit maps, are described in this paper to avoid producing color circuit maps that are neither pleasing, nor legible and possibly inferior in quality to similar black and white circuit maps.

A good understanding of color and its principles is essential in order to designate a color scheme for the features on the circuit map. Color interactions, such as simultaneous and successive contrasts, have to be taken into account when designing color maps. Color harmony should also be considered, as long as it does not interfere with the functionality of the maps. Although much research material is available on the subject of color in cartography, no material has yet been presented on the use of color in the circuit map. Dent (1999) states:

> Certain standards for color use have been adopted for some forms of mapping, notably on USGS topographic maps and maps of other national mapping programs. No standards or rules for color use, except for a few conventions, exist for thematic maps. (p. 289)

In addition, dealing with color poses a great challenge to mapmakers because of the emotional, physiological, cultural, and psychological characteristics associated with color. According to Dent (1999), color is produced by physical energy, but our reaction to it is psychological. The concept of color harmony as depicted by the color wheel (Figure 1) is an objective conclusion, while the response to color is emotional; what is produced in an intellectual manner is not necessarily pleasing to the emotions. Man responds to form with his intellect and to color with his emotions; he survives by form and lives by color (Dent, 1999). Therefore, to ensure its acceptability by the circuit map users, the proposed color scheme will require modification over time, based on feedback from utility staff.

Figure 1 – Color Wheel, consists of 12 colors (Earth Sensing)



1.1 METHODOLOGY

In order to assign a set of colors for the circuit map features and to explore various color schemes that cartographers utilize for different types of maps and data, the available literature was reviewed to gain additional knowledge of color principles and their application in mapping and GIS. This also helped to determine which types of color schemes lend themselves to the circuit map.

A set of guidelines for using color in the circuit maps does not already exist; however, by studying the use of color in other areas of cartography, including GIS, a color guideline for use on the circuit map was established.

The internal structure of the circuit map was examined in order to organize a meaningful arrangement of the features on the circuit map and to divide different features of the map into various classes. Preliminary guidelines were established to represent different feature classes on the circuit map using distinguishable colors and to create a pilot area on the circuit map for evaluating the proposed color scheme(s) against a black and white circuit map. The pilot area was selected from the circuit map of downtown area of Palo Alto that encompasses most of the feature classes of the circuit map.

A hard copy of the pilot map was provided to 64 persons from the engineering, operations, and general utility staff, to examine the colors selected for the various features on the circuit map versus a black and white circuit map. The sample was divided into two groups of 32 persons: One group was asked to perform a series of tasks on the color pilot map, while the second group was asked to perform the same tasks on the black and white pilot map, as is normally done by cartographers. This task is described in more detail in the evaluation process section of this paper to test the functionality and efficacy of the circuit map. In addition, the sample was asked to complete a questionnaire on demographics and must complete a consent form, as required by San Jose State University's Human Subjects Institutional Review Board.[2]

An attempt was made to draw scientific conclusions from the task results as well as from answers provided to the questionnaire, using statistical analysis. The results obtained were used to confirm the hypothesis of superiority of color over black and white on an electric circuit map.

Since the hypothesis was confirmed, the suggested color schemes will be used to plot the circuit map for potential users once the entire circuit map is complete in the GIS environment. In time, the color schemes will be modified according to feedback from circuit map users.

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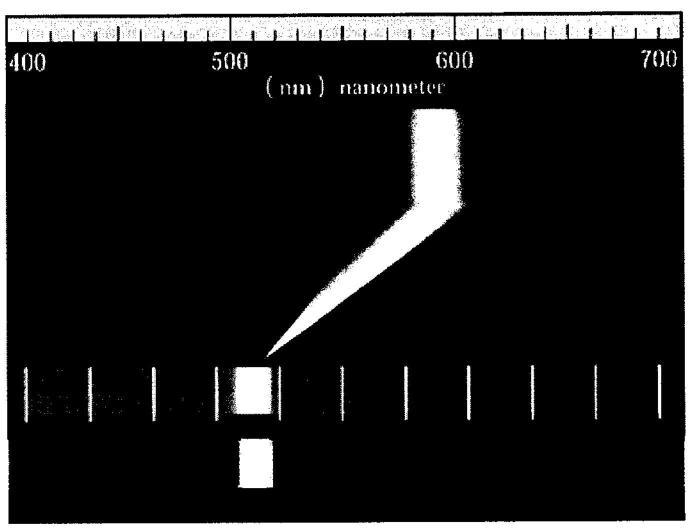
[2] This Board is required to review and approve any testing that involves human subjects, to ensure that the human subjects are protected from any possible risk and harm.

CHAPTER 2

2.0 LIGHT, COLOR, AND VISION

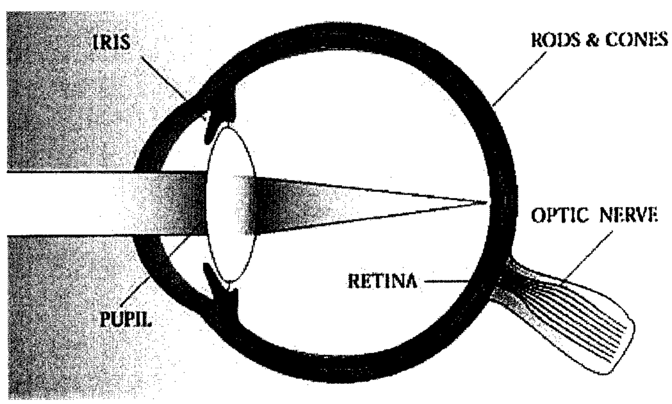
Color becomes possible only when light enters the eyes of an observer with an appropriate nervous system. Color does not exist in darkness. Light is a part of radiant energy, or the electromagnetic energy spectrum. As human beings, our visual system can see from 380 to 760 nanometers (1,000,000,000 nm equals one meter) on the electromagnetic wavelength (Konrad, Kauskopf, & Beiser, 1991), which is specified as visible light (Figure 2). The eye cannot see shorter-wave radiation, such as ultraviolet light or gamma rays, nor can it sense longer-wave energy, such as microwave radiation and television signals.

Figure 2 – Visible Light (Scitex Solutions)



Visible light links the anatomy of the human eye and the part of the brain that controls vision and color perception to the nature of light and color. Color is sensed when light is reflected back from an object to the eye. When light passes into the eye (Figure 3), the iris regulates the amount of light that flows through the lens to the retina. The retina, which is considered to be part of the brain, is a complex nerve structure containing light-sensitive receptors that are responsible for translating incoming light into nerve impulses. Because of their physical appearance, these receptors are known as rods and cones (Figure 4).

Figure 3 – Visual System (Scitex Solutions)

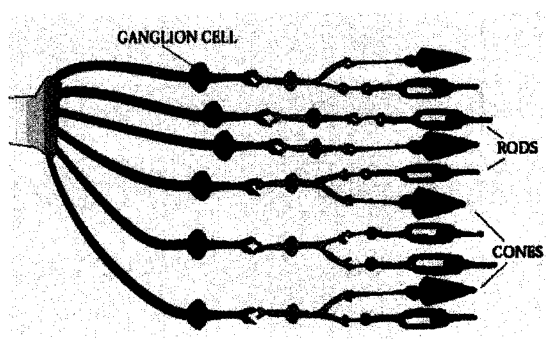


The rods, which are responsible for night or low light vision, are sensitive to a broad range of light intensities. However, they do not distinguish color.

On the other hand, the cones function in daylight and contain light-sensitive chemicals called photo pigments. The photo pigments contribute to color sensation. In addition, cones are sensitive to different wavelengths, which the brain interprets as color. Through adjustments made by the cones, objects generally retain their color when viewed in different light. This phenomenon is called color constancy (Green, 1999).

The circuit map will be viewed under three different types of light sources: outdoor sunlight, indoors incandescent or fluorescent light. Sunlight has all the wavelengths in equal amounts; incandescent light on the other hand shifts toward red, while fluorescent light shifts toward blue (Green, 1999). Color constancy helps the circuit map users to see the same feature colors in the office environment where indoor incandescent or fluorescent light dominates, and outdoor in the field where sunlight dominates.

Figure 4 – Rods and Cones (Scitex Solutions)



The information from the rods and cones travels along the optic nerve to the brain. What the brain sees is the experience of the viewer and the arrangement of the rods and cones on his retina.

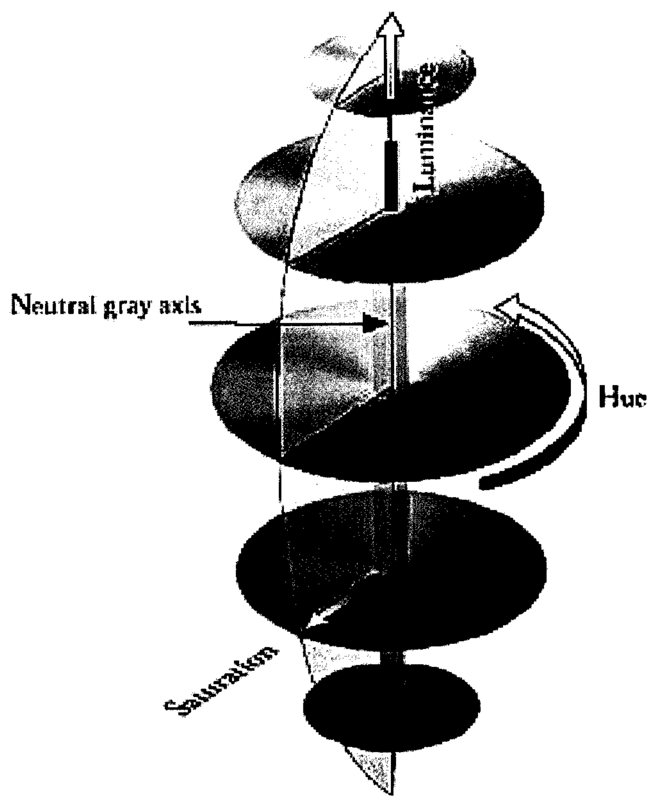
The eye contains three types of cone receptors. Each receptor is sensitive to about one-third of the visible spectrum: red light, green light, and blue light. The color of an object depends on how much red, green and blue light is reflected to the eye. Black is perceived when no light is reflected to the eye. White is perceived when red, green, and blue light is reflected to the eye in equal amounts. Abnormality in any of these three types of cones causes colorblindness. According to Green (1999), there are seven types of colorblindness, and the overall percentage of colorblindness is about seven percent in men and less that one percent in women. Colorblind people can see lightness differences and a wide range of hue differences. Red-green colorblindness is the most common color impairment. The following pairs of hues do not confuse people with the most common types of color impairments: red-blue, red-purple, orange-blue, orange-purple, brown-blue, brown-purple, yellow-blue, yellow-purple, yellow-gray, and blue-gray (Brewer, 1999). By carefully selecting the colors for the adjacent circuits the more common types of colorblindness can be addressed.

In addition, symbols, shapes, sizes, line styles, character styles, scale, and all details regarding the appearance of the circuit map are elaborately being designed. This enables all employees to easily use and understand the circuit map, including those with color vision impairment.

As a perceptual and graphic arts phenomenon, color has three dimensions: hue, saturation, and value. Figure 5 illustrates the color-space as a three dimensional model to describe the three dimensional relationship of hue, chroma (saturation), and value. Hue refers to the name of a color. Each hue has its own wavelength in the visible spectrum. Hues can be shown on a color wheel, and are suitable for qualitative and categorical differences on a map. The term luminance (value) describes the differences in the intensity of light reflected or transmitted by a color. Value is the quality of lightness or darkness of a color, and is more suitable for quantitative differences. Saturation (chroma) refers to the strength of a color, or how far it is from neutral gray. Saturation is more desirable for figure to ground contrast as well as quantitative differences (Brewer, 1999).

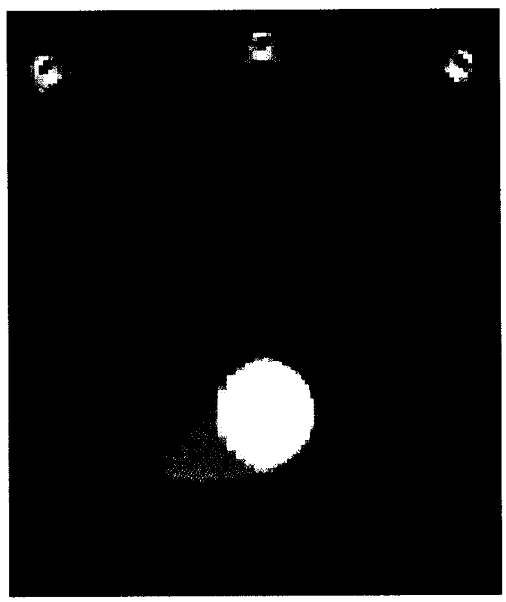
Each hue, value, and chroma triplet defines a unique color. The grays are located on the luminance axis where saturation is zero. For any luminance amount there is a plane, consisting of all possible hues, in which each hue varies from its maximum saturation state to its minimum saturation state. All three dimensions of color must be utilized, when assigning colors to the features on a circuit map.

Figure 5 – Hue, Saturation (Chroma) & Luminance (Value) System (Scitex Solutions)



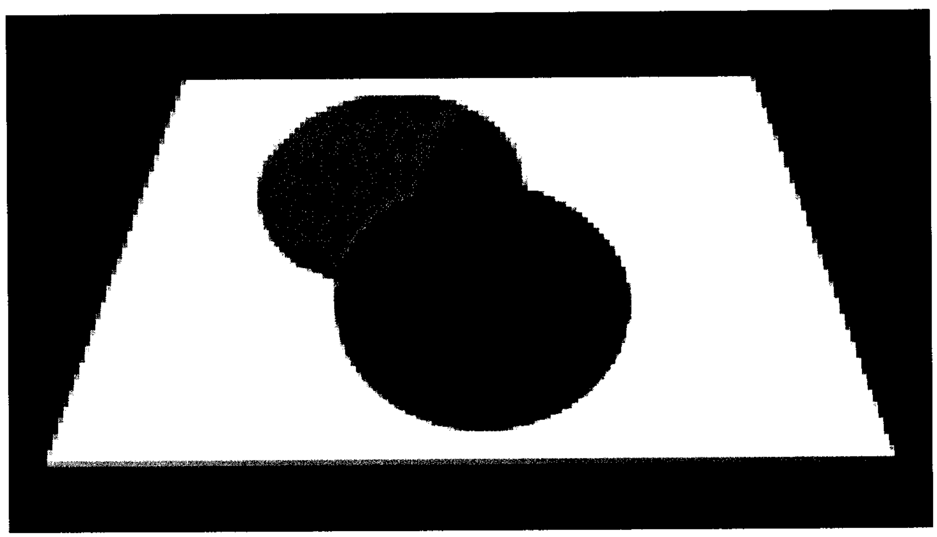
According to Monmonier (1991), personal computers are a source of poor color maps. Inexperienced mapmakers often mimic printed maps on a computer, due to their lack or limited knowledge of electronic displays and additive colors. Therefore, an uninformed map designer could be creating a color map that may be inferior to a similar black and white map, difficult to read, and not appealing to map users. Color monitors have dark backgrounds, as opposed to the more familiar white background of paper maps. Color monitors use dark backgrounds because video graphics with too much white background can potentially bloom and irritate the eye.

Figure 6 – Additive Colors (Apple Colorsync)



There are only two basic methods to reproduce color: additive and subtractive. Both processes are based on using three primary colors to create all other colors. The additive color process begins with black, or the absence of light, and therefore no color (Figure 6). It involves transmitted light before it is reflected by a substrate. With transmitted light, mixing the three primary wavelengths of light (red, green, and blue) in different combinations can produce all the colors of the rainbow. Any two of the primary colors mixed together will produce a third color, commonly referred to as a secondary color. Red and green projected together produce yellow; red and blue produce magenta, and blue and green produce cyan. Combining the three primary colors in equal amounts produces white. Color monitors, color scanners, and color television screens emit light. Therefore, they utilize the additive color method, which is used for viewing the circuit map on a color monitor.

Figure 7 – Subtractive Colors (Apple Colorsync)



The subtractive color process on the other hand is based on light reflected from an object that has passed through pigments or dyes that tend to absorb or "subtract" certain wavelengths from the reflected light, thus allowing other wavelengths to dominate (Figure 7). The primary subtractive colors –cyan, magenta, and yellow– when combined, can form red, green, and blue as secondary colors. Combining the ideal subtractive primaries in equal amounts produces black.[3] Color printers and color plotters use the subtractive color principle, which is employed for producing electric circuit maps.

Color harmony may be achieved by understanding the color wheel (Figure 1). The three primary colors of red, blue, and yellow are placed in an equidistant triangular format around a circle. At the halfway mark between each primary color lie the secondary colors, derived by mixing two primaries together in an orderly fashion around the circle. The secondary colors are orange, green, and violet. On each side of the secondary colors lie the intermediary colors. They exist as a result of mixing a primary and a secondary color together. These colors are named red-orange, yellow-orange, yellow-green, blue-green, blue-violet, and red-violet. Therefore, the total number of colors on the color wheel is 12. Colors on opposite sides of the color wheel (complementary colors) tend to be harmonious. Adjacent colors on the color wheel, and colors of the same hue with different saturation and value, also achieve harmony (Dent, 1999). Therefore, this principle will be considered when selecting colors for the features on the circuit map.

[3] In reality a pure black is not produced in this manner. For this reason, in addition to cyan, magenta, and yellow ink cartridges, a black ink cartridge is added in color printers and plotters to ensure that a high quality black color is available.

2.1 SYSTEM COLORS AND COLOR SCHEMES

Advantages and limitations of the various system colors and color schemes must be considered when assigning a color to features within the circuit map. A range of color schemes is available in cartography, however, only the color schemes suitable for circuits maps will be discussed and considered. In their paper, "Color Representation of Aspect and Slope Simultaneously", Brewer and Marlow (1993) used the HVC color system to specify 25 color appearances for the aspect and slope of topographic maps. She did that using equal intervals of value and saturation for depicting aspects and slopes. However, this type of color scheme, in which the color of the map gradually changes from one point to the next point, cannot be considered when selecting colors for features on the circuit map, where different circuits must have distinctly different colors; the type of information and data shown on the circuit map do not lend themselves to such a color scheme.

In addition, as illustrated in Figure 8, there are 64 predefined pen numbers within the City of Palo Alto GIS. Each pen number has its own color, which is created by way of subtractive method with an already assigned HVC that can be used for line features. As a result, line feature colors will be selected from the available City of Palo Alto GIS colors that are defined by pen numbers 0 to 63. Figure 9 and Figure 10 show available colors for closed polygons that can be used for the shaded polygons.

Figure 8 – Available colors to assign for circuits in the GIS environment

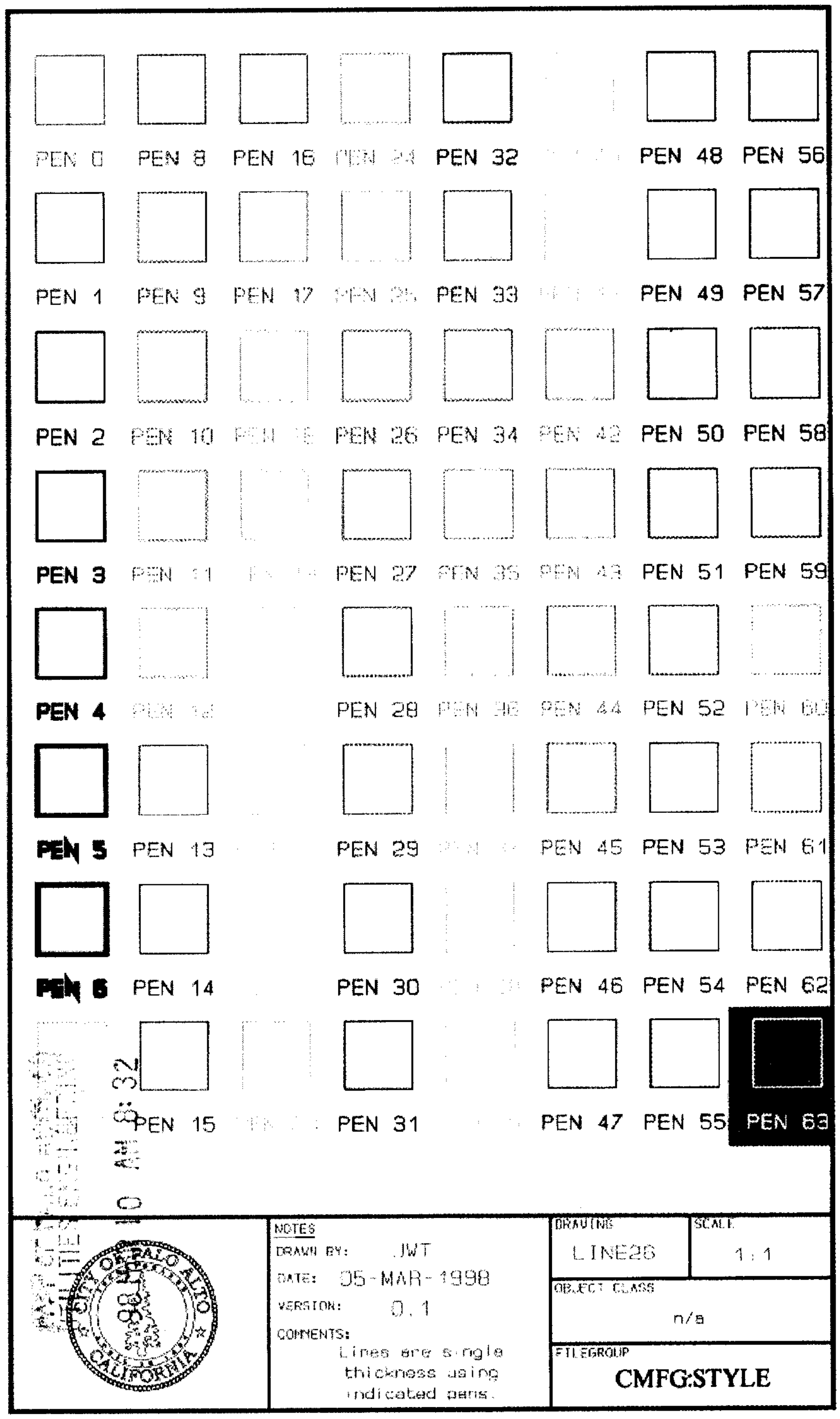


Figure 9 – Available colors for the shaded polygons (series #1)

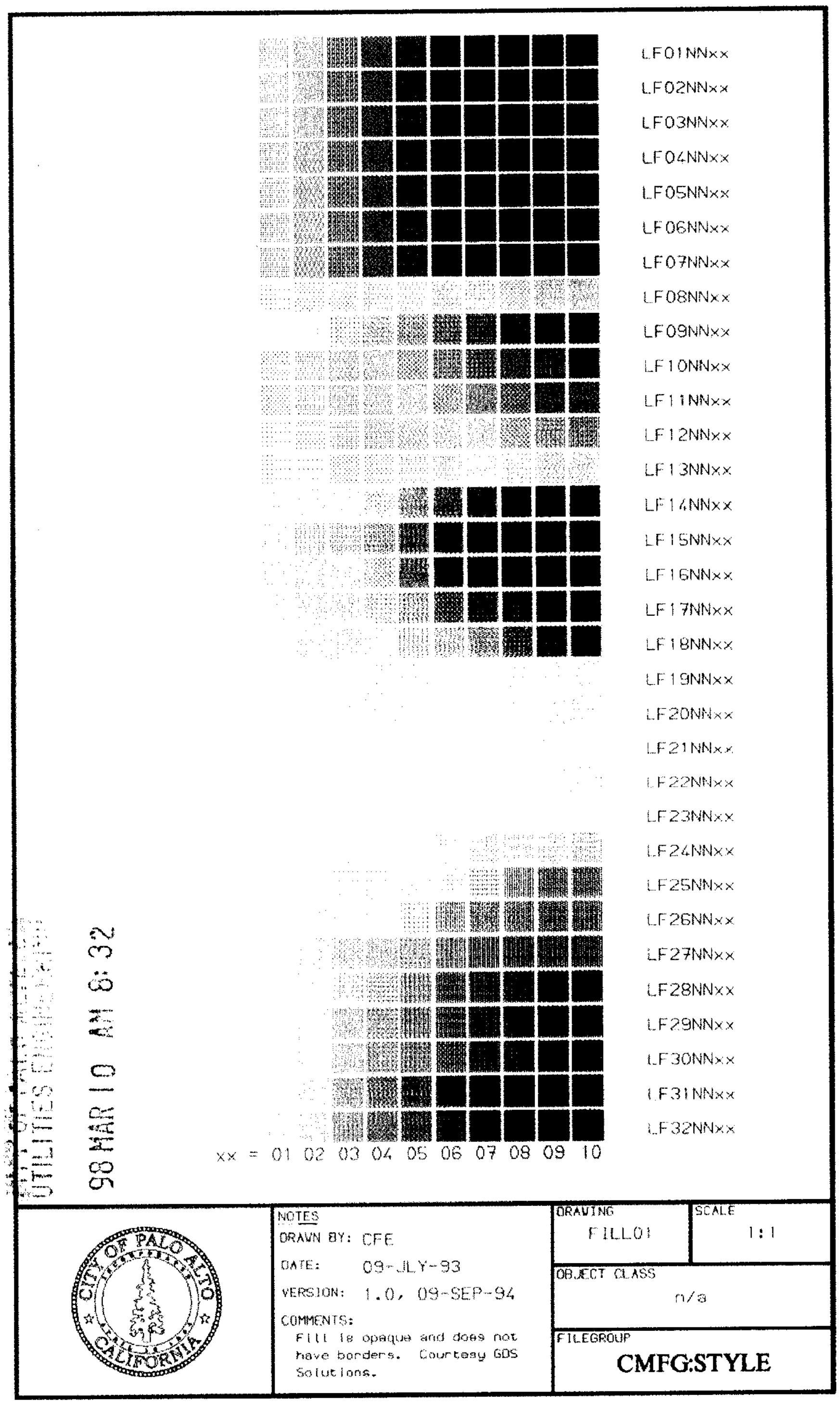
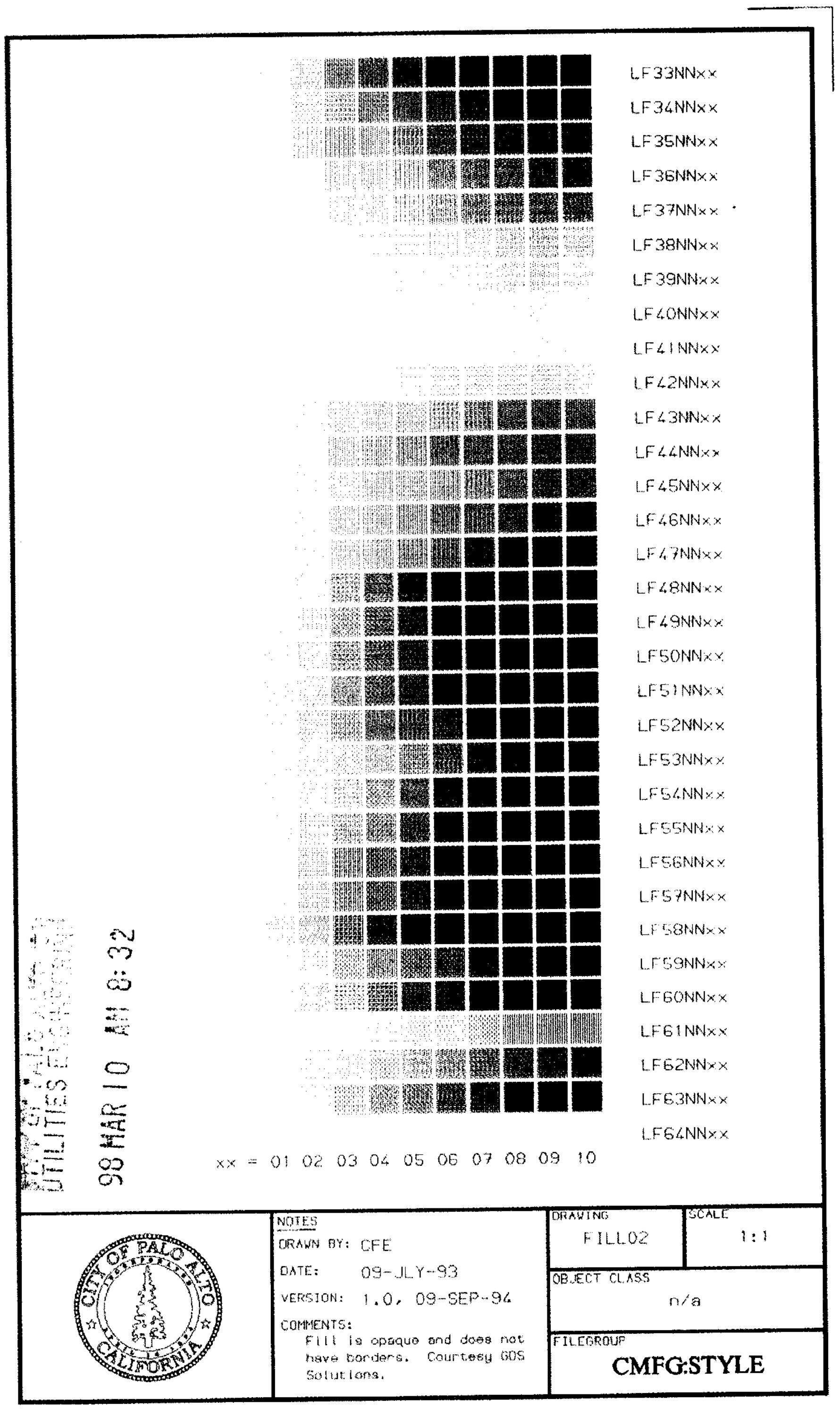


Figure 10 – Available colors for the shaded polygons (series #2)



CHAPTER 3

3.0 COLORING THE CIRCUIT MAP

In order to develop a color scheme for features of the circuit map, a better understanding of the circuit map is required. The electric distribution circuit map shows the flow of electric power from substations to the distribution transformers via feeders. These feeders are labeled according to their substation names and their primary voltages:

- 4KV feeders are numbered from 1 to 11.
- 12KV feeders are numbered from 20 to 29.

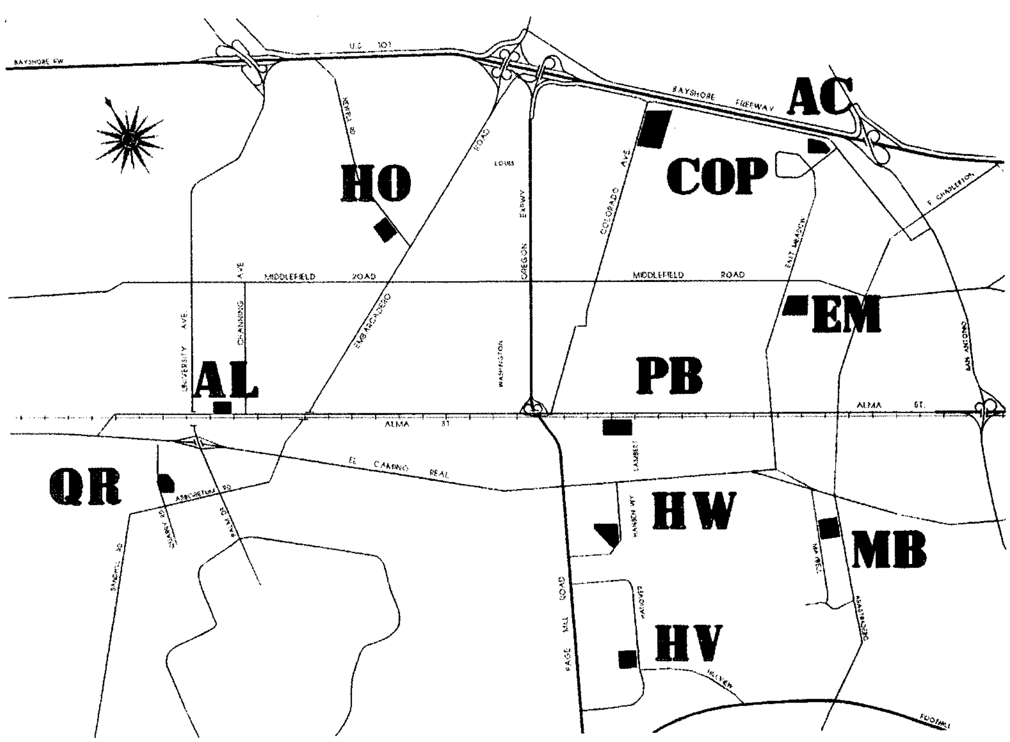
For example, QR-2 is a feeder coming out from the Quarry Road Substation, and is rated 4KV; AL-20 is a feeder exiting from the Alma Substation, and is rated 12KV.

Shaded polygons represent underground electric facilities to allow users to distinguish between underground and overhead areas. An overhead circuit runs from one power pole to the next power pole. An underground circuit, on the other hand, runs from one manhole to the next manhole, inside a covered trench.

The circuit map is used by supervisors and managers for planning purposes, by operations personnel for switching circuits, and by engineers and estimators for routine project design. Currently, the Utilities Department is developing a new circuit map in the GIS environment based on the approved model.[4] The circuit map is very complex and contains a multitude of information. The challenge is to enhance the quality of the circuit map for the engineering and operations staff. The goal of this paper is to establish a color scheme that will help display the features on the circuit map most clearly. There are five different categories that must be color-coded. These are:

1. Base Map
2. Shaded polygons to represent underground electric utility
3. Text
4. Circuits
5. All other features (Switches, Load breaks, Transformers, etc.)

Map 2 – City of Palo Alto's 10 electric power Substations



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[4] Discussion of the approved model for the circuit map is not within the scope of this paper.

3.1 BASE MAP

In addition to assigning colors to the different circuits, a color must be assigned to the base map. The base map exhibits the outline of Palo Alto streets (as defined by curb or pavement edges) and their names. The base map should not stand out in the circuit map since the circuits are the main objective of the circuit map. A color, such as black, which stands out and has a very strong figure-to-ground contrast, is not suitable for depicting the base map, as demonstrated in Map 3. Therefore, the base map should have a lighter, low saturated color that is visible in the background, as illustrated in Map 4.

Base map color also affects color choices for circuits. Yellow does not stand out well on a white medium, in this case the white plotting paper. According to Brewer (1994B), "A pure yellow will not be as visible on a white background as red, green, or blue." A circuit that is displayed in yellow on white plotting paper is hardly visible and can be difficult to follow and trace, as seen in Map 5.

Since the number of distinguishable saturation levels is lowest in yellow, its use would not be an appropriate choice for a circuit, which is the major feature of a circuit map. Green (1999) asserts:

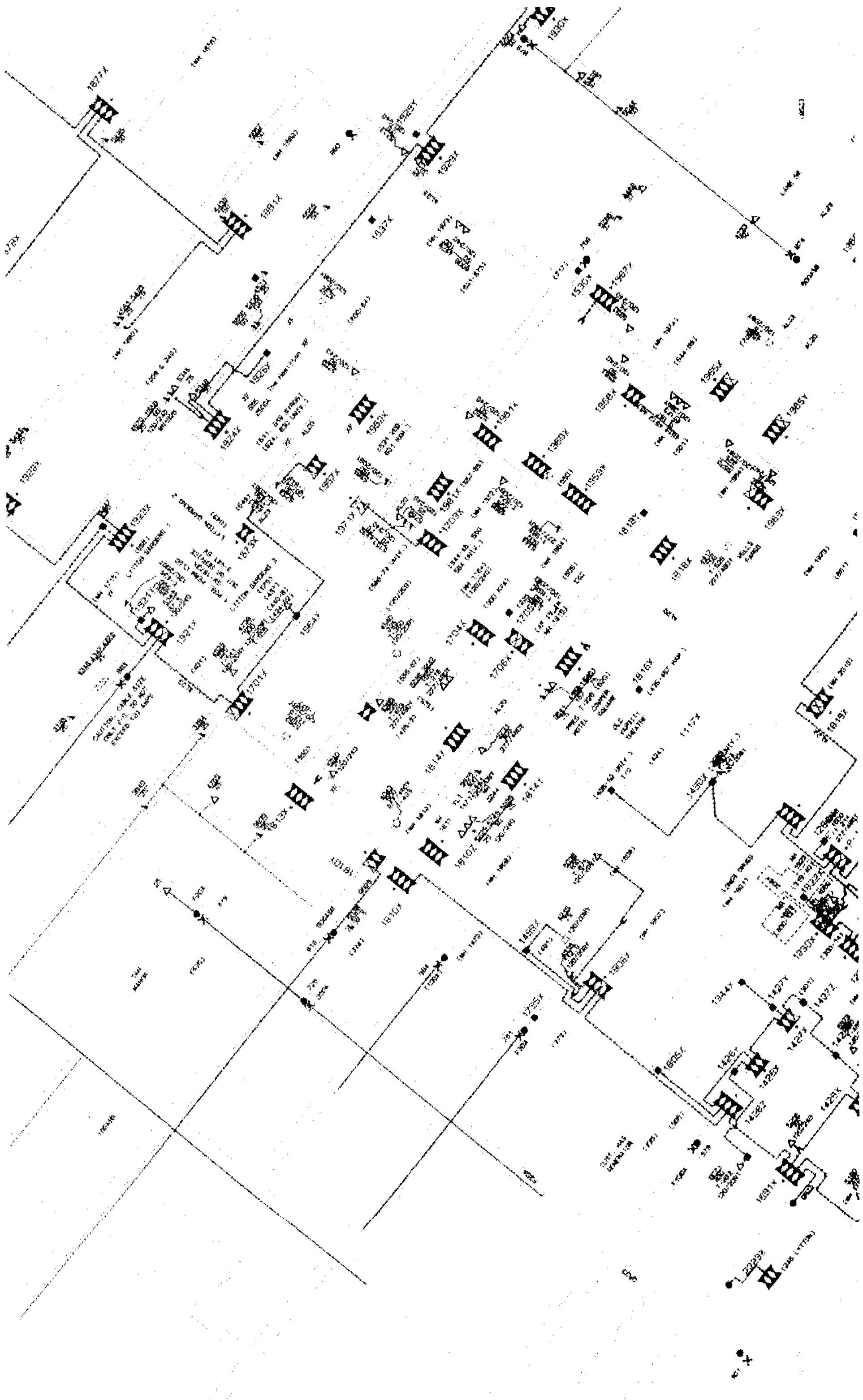
> The number of distinguishable saturation levels is smaller in yellow than in the rest of the spectrum. One study concluded that there are only 10 saturation steps around yellow with the number gradually rising as wavelength increased or decreased. (section 2.8, para. 1)

Yellow, however, is one of the main hues in a color space and many other colors are created using the color yellow. It would be best utilized for a background feature of the circuit map. Therefore, as shown on Map 6, the use of yellow is highly recommended for the base map. In addition, yellow is a suitable color for the base map because it is considered a warm color. While yellow does not stand out on a white background like other hues on the color wheel, its warmth gives it a figural quality. According to Dent (1999), warm colors (such as red, orange, and yellow) tend to take on figural qualities, which are more important map elements, better than cool colors (such as green, blue, and purple), which tend to make good backgrounds, which are less important map elements. In this case, the base map (yellow, warm color) will take the role of the figure when juxtaposed with the shaded polygon (a low, saturated, cool color), which will assume the role of the background. Therefore, the best place to use a yellow hue is in the base map.

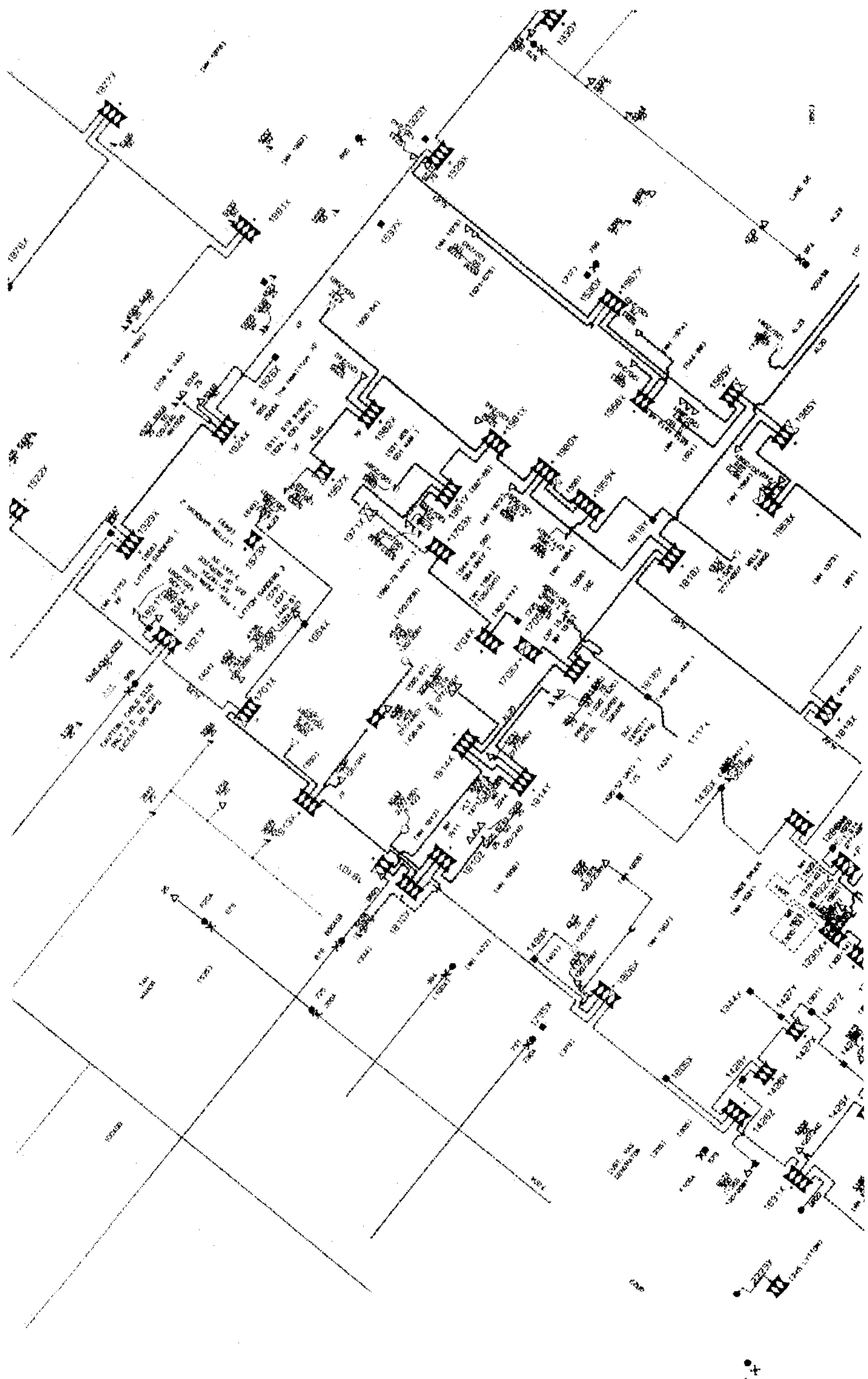
Map 3 – Dark, strong base map overwhelms the circuits

Map 4 – Light, low saturated base map allows circuits to stand out

Map 5 – A yellow circuit on a white background, does not stand out



Map 6 – Yellow base map on white backdrop allows circuits to stand out



3.2 SHADED POLYGONS FOR UNDERGROUND ELECTRIC UTILITY

Based on the department-approved model for the circuit map, a shaded polygon indicates areas that contain underground electric utility circuits. The shaded polygon allows the utility staff to quickly determine whether a region is served by an underground or an overhead circuit. A suitable color should not interfere with the visibility of the circuits, base map, text, or other features. While these shaded polygons should be visible, they should not stand out against the circuits. Shaded polygons have the lowest hierarchical rank in the circuit map, and as the background of the circuit map, they must have a cool color; (cool colors make good grounds, while warm colors tend to take on figural qualities.[5])

Another characteristic to consider when selecting a color for the shaded polygon is the advancing and retreating nature of a color. Colors, such as red, with a longer wavelength tend to have advancing (figural) traits, while colors with a lower wavelength, such as blue, have retreating (background) traits. In addition, saturated colors advance, while less saturated colors recede. This is further explained by Dent (1999), as advancing colors should be applied to figural objects and retreating colors to ground objects. In terms of saturation, deep or highly saturated colors advance; less saturated colors recede.

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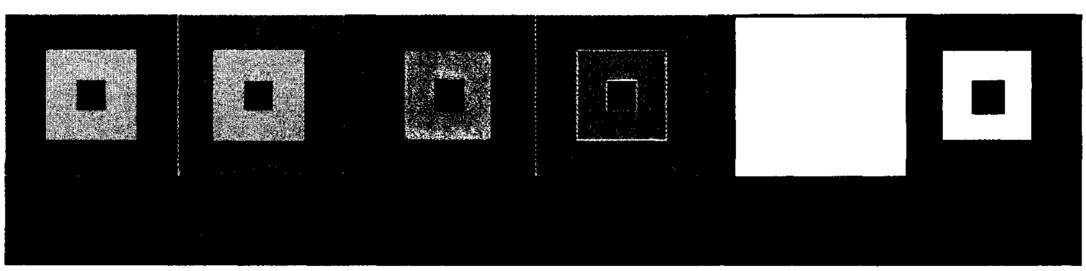
[5] Dent (1999)

The next color characteristic to consider for shaded polygons is the simultaneous contrast. A background color will induce its complementary hue (colors on opposite side of the color wheel) into an object. According to Brewer (1992):

> Simultaneous contrast is the induced enhancement of differences between a given colour and surrounding colour; it is the effect of the surround on the colour one perceives...A medium gray with a black surround looks lighter than the same gray with a white surround. (p. 20)

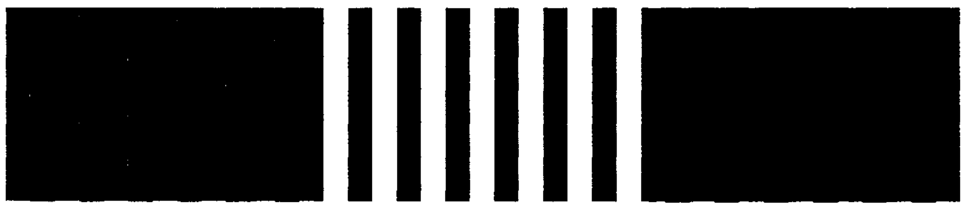
If the background is green, for example, the object will appear more red, as illustrated in Figure 11. The effect is strongest when the background is much more saturated and brighter than the object. This phenomenon is called simultaneous color contrast. To minimize the induced hue and saturation effect, a less saturated, grayish, light color should be selected for the shaded polygons. Another color phenomenon to consider is successive contrast afterimage, which is prolonged exposure to a particular color and has the same effect as the simultaneous contrast (Kuehni, 1983).

Figure 11 – Simultaneous Contrast (Green, 1999)



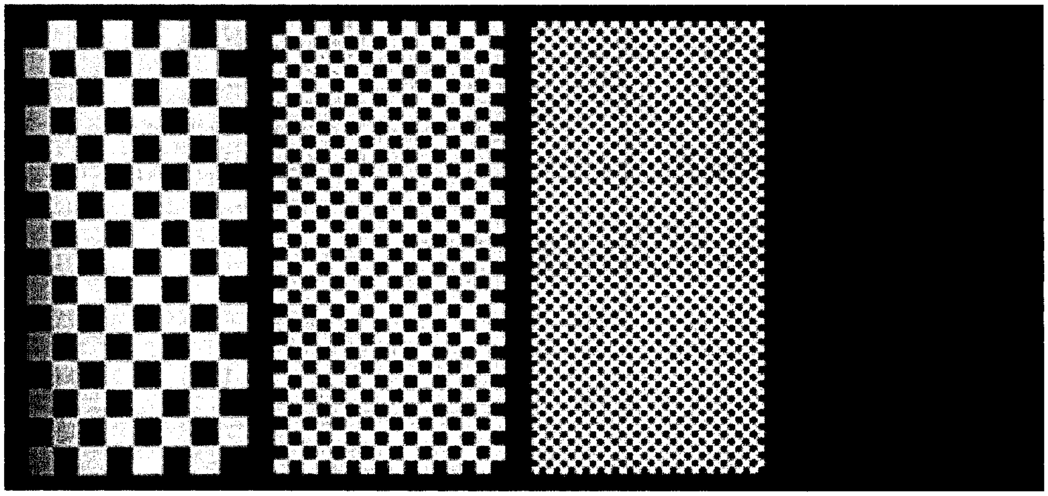
Assimilation also affects color perception. Assimilation is the opposite of simultaneous contrast. The background spreads into the object instead of inducing contrast. As demonstrated in Figure 12, the white bars spread to make the blue lighter, and the black bars spread to make the same blue appear darker (Green, 1999). Color assimilation occurs in fabrics with a small pattern or where different colored threads are interwoven. If an assimilation effect is not desired, each color should be isolated with a black, white, or a neutral outline (Luke, 1996).

Figure 12 – Assimilation effect (Green, 1999)



Assimilation affects the overall color and, therefore, the mood of the circuit map. The combined effect of the available colors on the circuit map appears the same, as the mixture of all colors used. When a color circuit map is viewed from a distance at which details appear distorted and cannot be resolved, map colors begin to blend into each other and appear as one color that would be perceived as the dominant color of the circuit map as seen in Figure 13. By periodically changing the colors of shaded polygons and base map with every new revision of the circuit map, the mood of the circuit map can be changed. This enables the users to quickly distinguish between different revisions.

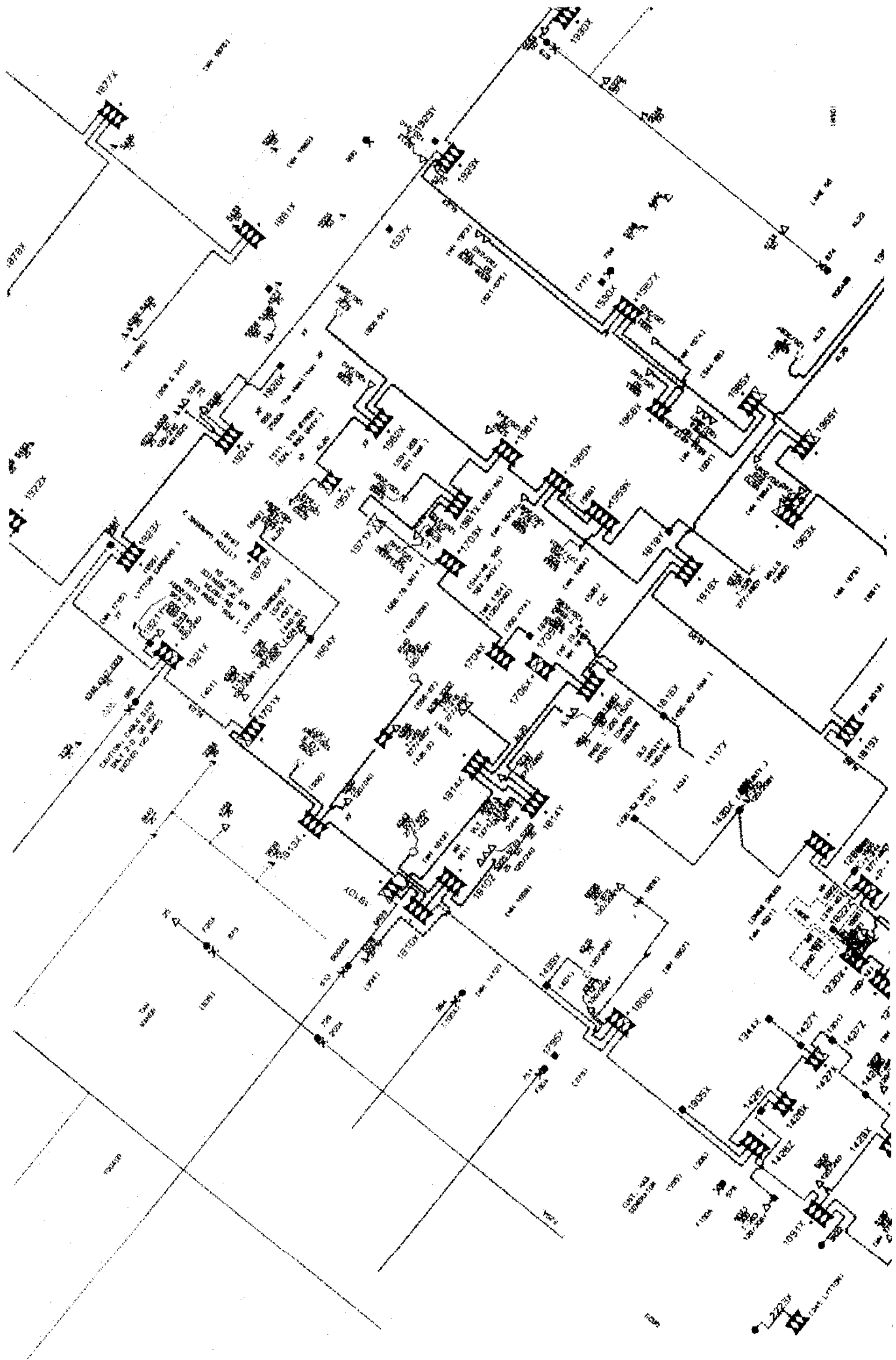
Figure 13 – Viewed from distance, colors blend and appear as one color (Palmer, 1999)



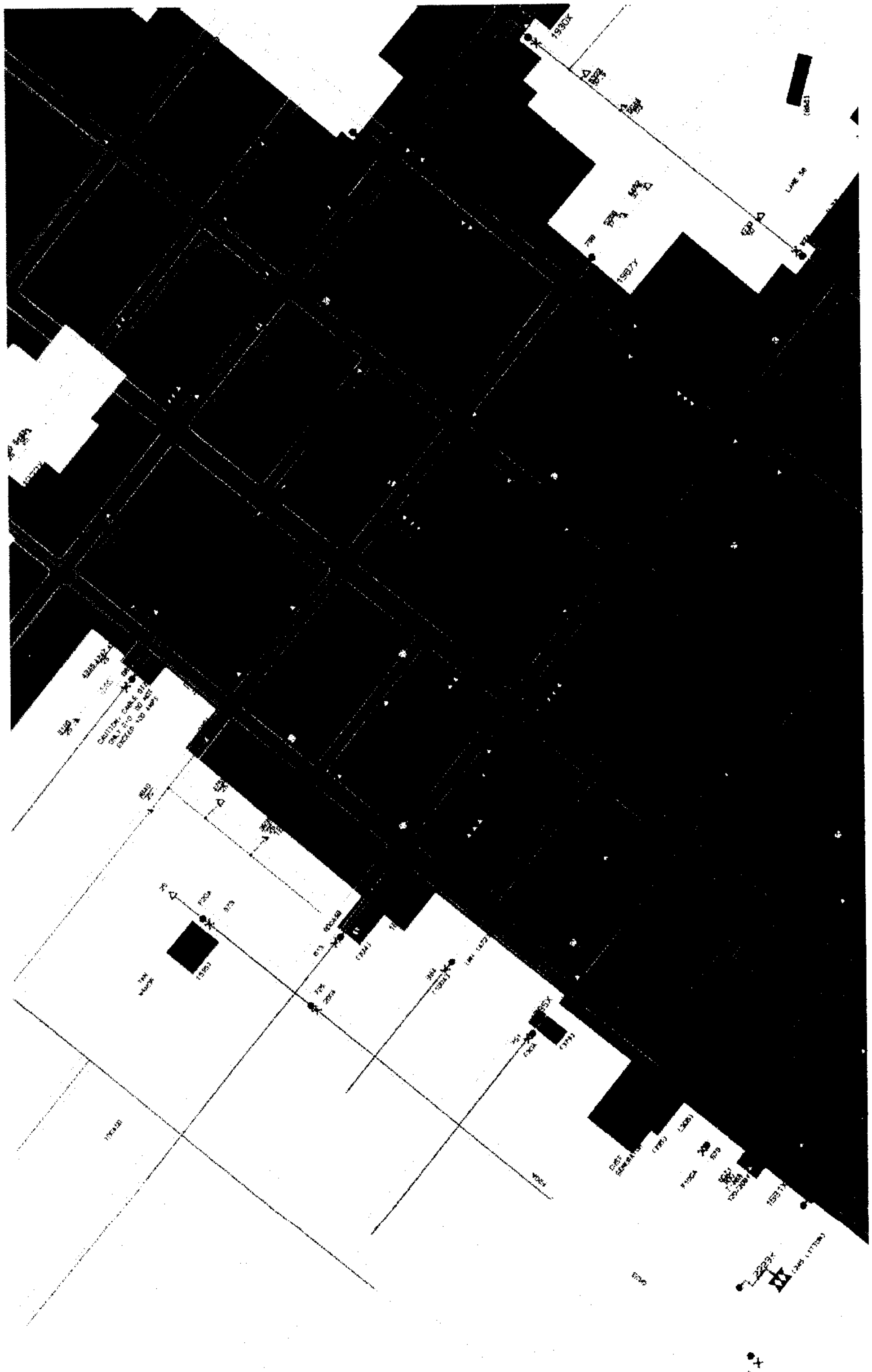
As demonstrated in Map 8 and Map 10, a dark or highly saturated color is not suitable for shaded polygons. These colors assume a figural role and tend to interfere with the legibility of the circuits and other features of the maps. Map 7 and Map 9, both illustrate the suitability of light and less saturated colors for the shaded polygons.

A suitable color for the shaded polygons is a cool, less saturated color with just enough contrast with the white medium. Therefore, a grayish, cool, light color such as the one used in Map 7, has to be selected for the shaded polygons.

Map 7 – Cool, low saturated color, desirable for shaded polygons

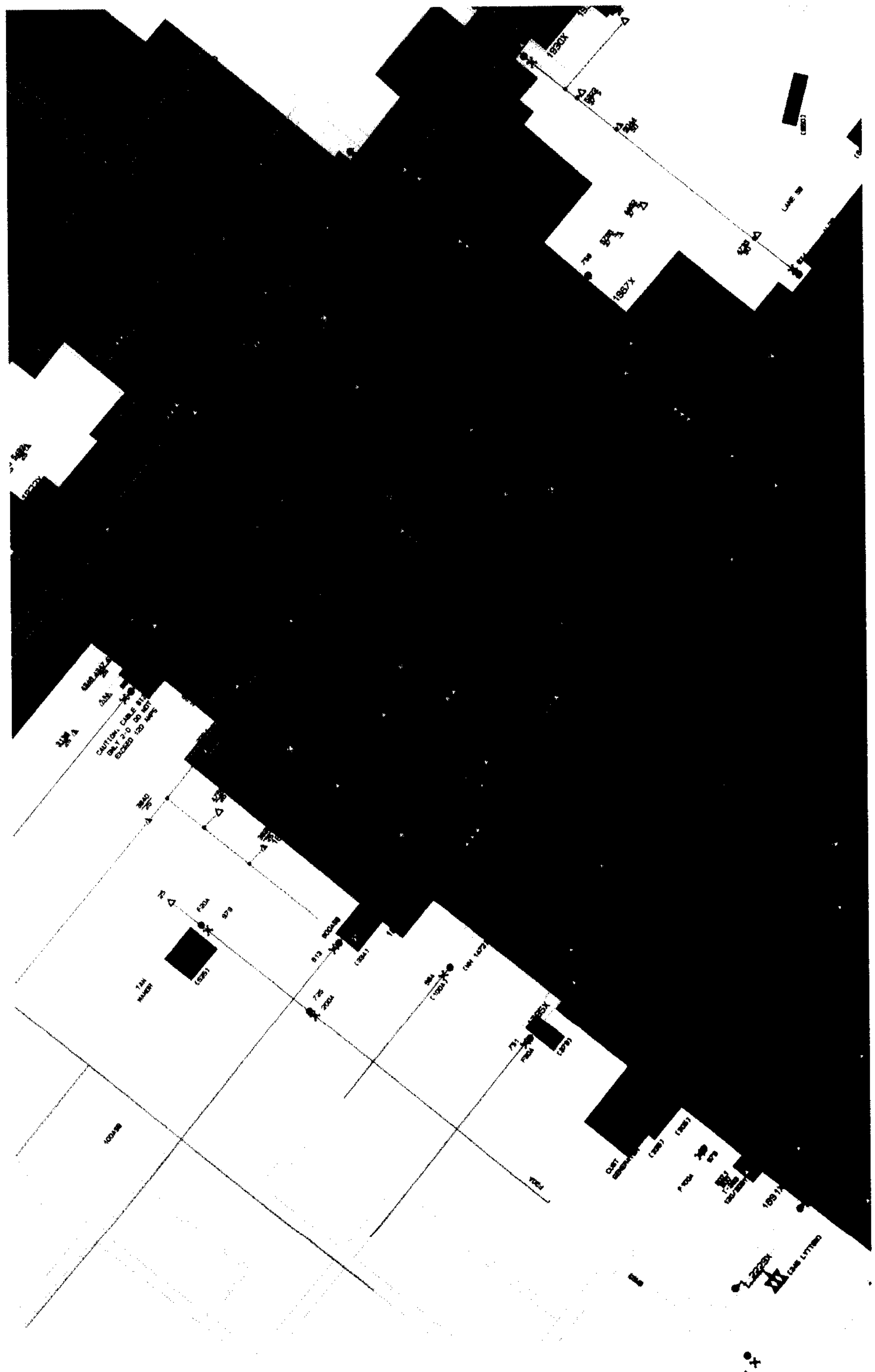


Map 8 – Warm, fully saturated color, unsuitable for shaded polygons



Map 9 – Cool, low saturated color, preferable for shaded polygons

Map 10 – Dark color, inappropriate for the shaded polygon



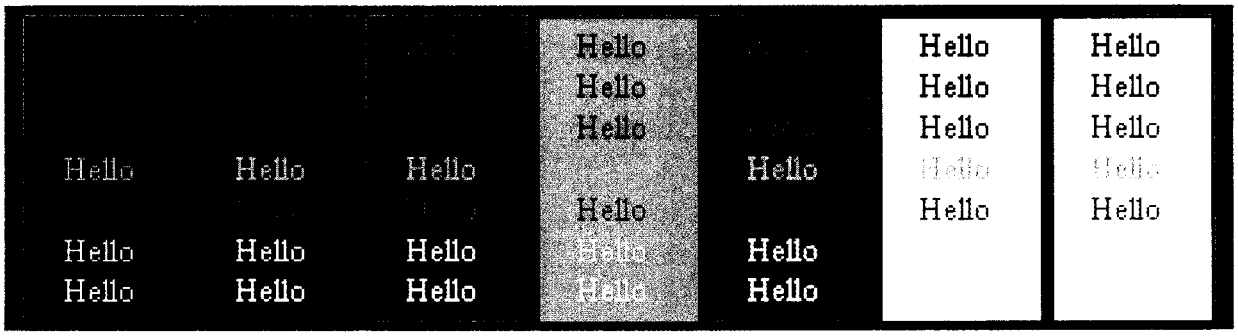
3.3 TEXT

Text is another feature category to be considered in the circuit map. Text can be divided into two groups:

1. Text related to the circuit features, such as a transformer number, which is considered primary text, is the more important of the two and should be more visible.
2. Text related to the base map, such as a street name, should be visible to the map viewer; however, due to its visual hierarchy, it assumes a secondary role.

According to Green (1999), high achromatic contrast maximizes text legibility. Color cannot produce fine detail. The chromatic system has one-fifth the spatial resolution of the achromatic system. For example, black (no color) text on a white medium is very visible and legible, and black is therefore the most suitable choice for the circuit feature text. On the other hand, gray is a color between black and white in value; therefore, a visible shade of gray is recommended for the base map text. Using different backgrounds, Figure 14 shows the legibility of various text colors. The best combinations have the two brightest colors, white and yellow, contrasted with the two darkest colors, black and blue.

Figure 14 – Text visibility relative to its background color (Green, 1999)



3.4 CIRCUITS

Circuits are the primary functional element of an electric circuit map; they are the reason that a circuit map exists. Therefore, if all the circuits on a map were to be black or any single color in a crowded circuit map environment, the human eyes could not easily follow and trace any particular circuit. In this situation, the eyes could easily jump from one circuit to another while tracing this particular circuit. Therefore, color must be used in order to distinguish between the different circuits on a map as well as to avoid tracing the wrong circuits. Similarities and differences within circuits must be identified so that the appropriate hues, which show categorical differences (Brewer, 1999), can be assigned to them.

According to Dent (1999), the color dimension most appropriately used on the qualitative map is hue, such as the different and distinct colors that are employed in a land use map. While value is more suitable for quantitative differences, such as in a world population map that starts from a very light shade of a color for less populated countries to a very dark shade of the same color for the heavily populated countries. Hue shows nominal classification well and is not usually associated with quantity of data. Green (1999) asserts that hue shows categorical distinctions, and color is an ideal way to signal that objects have similar or different meaning, function, and importance. He states that color discrimination increases when all three dimensions of color (Hue, Value, Chroma) are used. Hue discrimination becomes more difficult as colors become less saturated, and declines at lower levels of brightness.

Following are suggested methods used to arrange the circuits into different classifications so that the most suitable classification can be selected and a set of colors can be assigned:

- 3.4A – Classification by Voltage (Qualitative, Binary Scheme)
- 3.4B – Classification by Substation (Regional, Qualitative Scheme)
- 3.4C – Classification by Circuit Number (Sequential Scheme)
- 3.4D – Classification by Priority Number (Sequential, Qualitative Scheme)

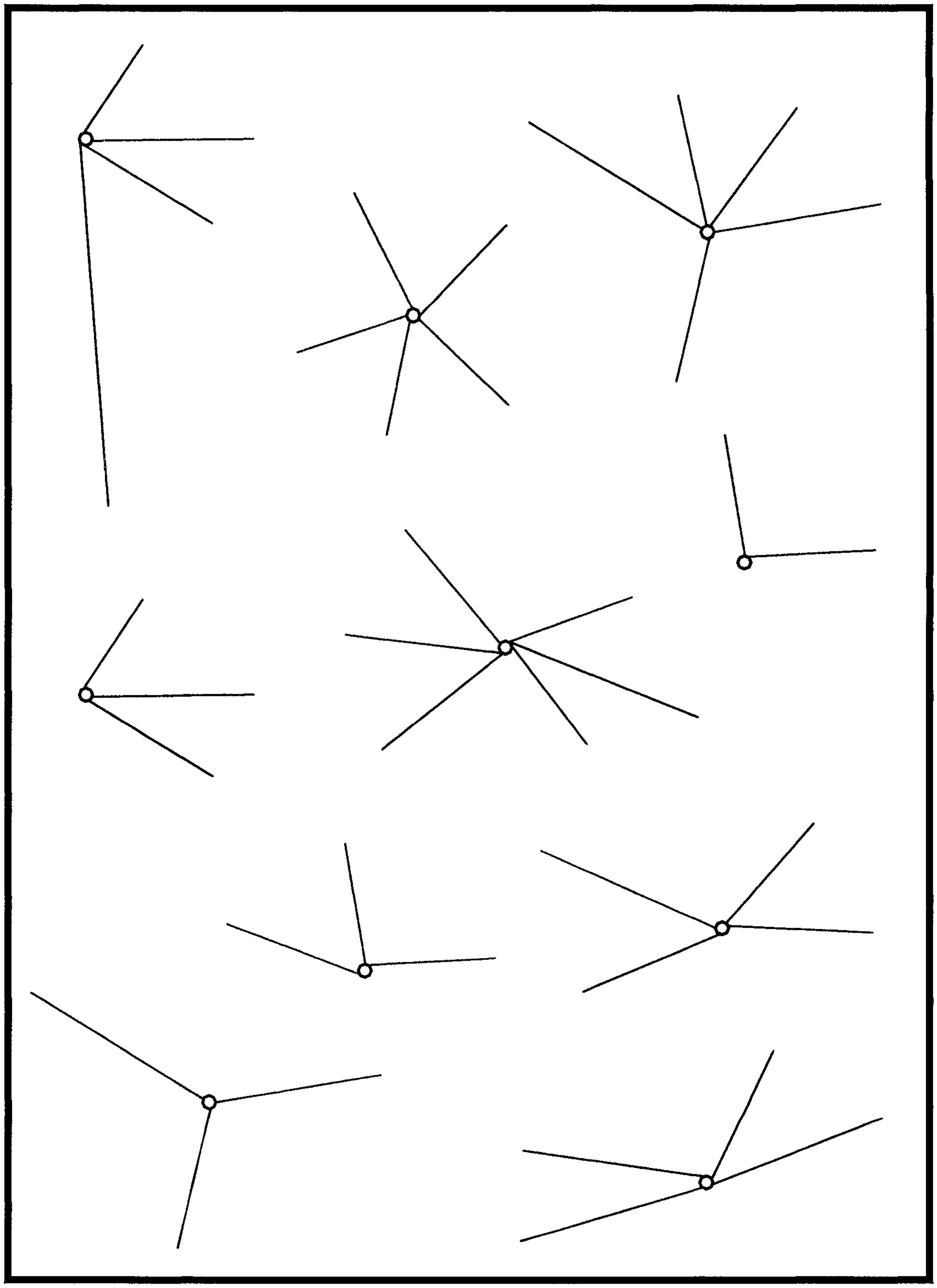
3.4A CLASSIFICATION BY VOLTAGE (QUALITATIVE, BINARY SCHEME)

Two complementary hues with sufficient contrast can be used for this binary, qualitative color scheme: one hue, such as red for the 12KV circuits, and a second hue, such as blue for the 4KV circuits. As shown in Figure 15 and Figure 17, this color pair will produce differences that can be read accurately by all map users (Brewer, 1996B). In this scheme (see Table 1), feeders are easily distinguishable by their voltage rating since the two colors used are based on voltage only. However, different feeders of a substation cannot be easily distinguished, other than by voltage rating.

Table 1 – Classification of circuits by voltage (Qualitative, Binary Scheme). Two colors are used: one color for the 4KV circuits; a second, different color for the 12KV circuits.

SUBSTATION ID	4KV FEEDERS (COLOR 1)	12KV FEEDERS (COLOR 2)
AC		20, 21, 22, 23, 24, 25
AL		20, 21, 22, 23, 24, 25, 26, 27
CO		20, 21, 22, 23, 24, 25
EM	1, 2, 3, 4, 5, 6	
HO	1, 2, 3, 4, 5, 6, 7, 8	
HV	5, 6, 7, 8, 9, 10	20, 21, 22, 23, 24, 25, 26, 27, 28, 29
HW	1, 8, 11	20, 21, 22, 23, 24, 25, 26, 27
MB	1, 2	20, 21, 22, 23, 24, 25
PB	2	20, 21, 22, 23, 24, 25
QR		20, 21, 22, 23, 24, 25, 26, 27

Figure 15 – A Binary Color Scheme, Qualitative



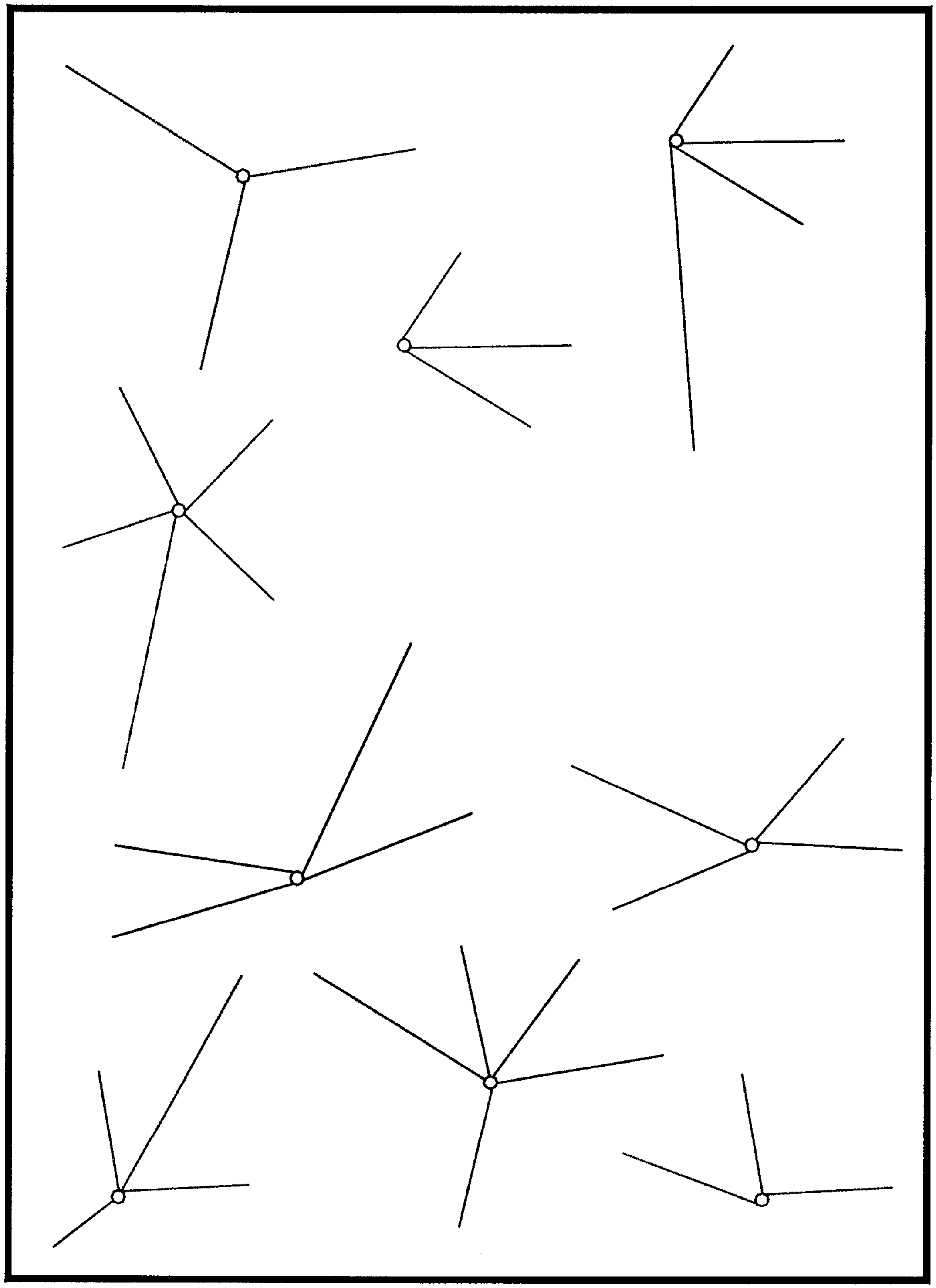
3.4B CLASSIFICATION BY SUBSTATIONS (REGIONAL, QUALITATIVE SCHEME)

With a regional color scheme, neighboring substation feeders will have the colors with most contrast relative to each other, as shown in Figure 16. From the 12 hues on the color wheel, 10 can be assigned to feeders of each substation (10 substations serve the City of Palo Alto). The adjacent substation feeders will assume the complementary color from the opposite sides of the color wheel, due to their hue contrast quality, with the exception of yellow. Yellow will not be used for the feeders; it is reserved for the base map, as explained in the base map section. A more extensive discussion on the color selection process is presented in classification "3.4D", which is priority based (sequential, qualitative scheme) color selection. In regional qualitative color scheme, feeders can easily be distinguished by their original substation. In addition, since the substations are regional, each region's feeders will have a different color. However, due to their proximity, different feeders of a particular substation cannot be easily distinguished. For example, tracing circuits around this particular substation would be more difficult than tracing to distinguish between circuits of two different substations. A summary of this classification is shown in Table 2.

Table 2 – Classification of circuits by substations (Regional Qualitative Scheme). Ten colors are used for the feeders: a different color for each substation.

SUBSTATION ID	FEEDERS	COLOR (10 Colors)
AC	20, 21, 22, 23, 24, 25	C01
AL	20, 21, 22, 23, 24, 25, 26, 27	C02
CO	20, 21, 22, 23, 24, 25	C03
EM	1, 2, 3, 4, 5, 6	C04
HV	5, 6, 7, 8, 9, 10 20, 21, 22, 23, 24, 25, 26, 27, 28, 29	C05
HW	1, 8, 11 20, 21, 22, 23, 24, 25, 26, 27	C06
HO	1, 2, 3, 4, 5, 6, 7, 8	C07
MB	1, 2 20, 21, 22, 23, 24, 25	C08
PB	2 20, 21, 22, 23, 24, 25	C09
QR	20, 21, 22, 23, 24, 25, 26, 27	C10

Figure 16 – A Regional, Qualitative Color Scheme



3.4C CLASSIFICATION BY CIRCUIT NUMBER (SEQUENTIAL, SCHEME)

As shown in Table 3, this scheme uses 21 colors and requires all feeders with the same number, such as AC-20, AL-20, CO-20, to have the same color. Since all feeders with different numbers have dissimilar colors, feeders of a particular substation can easily be distinguished. However, assigning 21 different colors to the circuits is not an easy task. Brewer (1992) asserts, limiting the number of colors by limiting the number of map categories is recommended to aid the designer in making color selections that are easily differentiated. In addition, limiting the number of colors to no more than 11 is recommended. According to Green (1999):

> The time required to search for information slowed after the use of 6 colors, but Smallman and Boynton (1990) found it possible to increase the number to nine colors, as long as they were widely separated. However, it would probably be a mistake to exceed the 11 basic color categories if color is to code conceptual distinctions. (section 5.9, para. 2)

Since this color scheme requires too many colors, it is not a practical color scheme. Therefore, in order to lower the number of feeder arrangements so that the number of required colors are decreased, a modified version of this scheme, which is classification by priority number (sequential, qualitative scheme) is introduced and recommended in section 3.4D.

Table 3 – Classification of circuits by feeder number - Sequential Scheme. Twenty-one colors are needed and all feeders with the same number have the same color.

FEEDER NO.	SUBSTATION ID	TOTAL NUMBER OF FEEDERS	COLOR (21 Colors)
1	EM, HO, HW, MB	4	C01
2	EM, HO, MB, PB	4	C02
3	EM, HO	2	C03
4	EM, HO	2	C04
5	EM, HO, HV	3	C05
6	EM, HO, HV	3	C06
7	HO, HV	2	C07
8	HO, HV, HW	3	C08
9	HV	1	C09
10	HV	1	C10
11	HW	1	C11
20	AC, AL, CO, HV, HW, MB, PB, QR	8	C12
21	AC, AL, CO, HV, HW, MB, PB, QR	8	C13
22	AC, AL, CO, HV, HW, MB, PB, QR	8	C14
23	AC, AL, CO, HV, HW, MB, PB, QR	8	C15
24	AC, AL, CO, HV, HW, MB, PB, QR	8	C16
25	AC, AL, CO, HV, HW, MB, PB, QR	8	C17
26	AL, HV, HW, QR	4	C18
27	AL, HV, HW, QR	4	C19
28	HV	1	C20
29	HV	1	C21

3.4D CLASSIFICATION BY PRIORITY NUMBER (SEQUENTIAL, QUALITATIVE SCHEME)

Classification of feeders by priority number (Sequential, Qualitative Scheme) requires establishing a color scheme based on the number of feeders as the primary factor and voltage (12KV, 4KV) as the secondary factor, as shown in Table 4. Greater prominence is given to 12KV circuits than to 4KV circuits; because the 4KV circuits are being converted to 12KV circuits and over time the 4KV circuits will be eliminated.

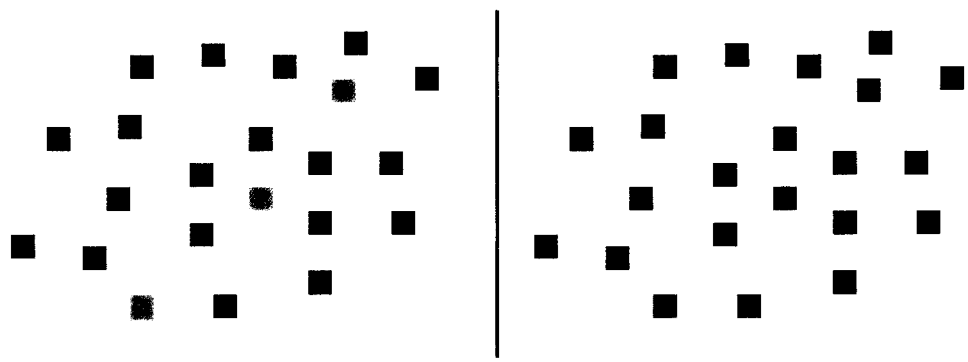
Most 12KV feeders with the same sequence number such as AC-20, AL-20, CO-20 would still have the same color. 4KV feeders however, will be arranged into two different groups, and will assume two dissimilar colors, but different from 12KV feeder colors. This compromise appears to be the most practical option. In this scheme, feeders with different numbers typically have different colors, thus making it easy to distinguish between most feeders of a particular substation. Furthermore, 12KV and 4KV feeders are easily distinguishable because no color is common between them. Although priority system used for this type of arrangement has, to some degree, solved the problem of color limitations of option "3.4C", circuits of lesser prominence, will still have similar colors.

To choose the colors for this scheme, the hues will be used in priority order. When the main hues are exhausted, hues with different saturation and value can be introduced for circuits with a lesser priority order.

Another factor in selecting color for circuits is the use of complementary colors. Complementary colors are colors on opposite side of the color wheel. An attempt should be made to use the colors with the most contrast in adjacent circuits. Dent (1999) states that contrast in the employment of color can lead to clarity, legibility, and better figure-ground development.

Thus, color combinations such as blue / orange would be suitable for adjacent circuits, while, combinations of red-orange / red, and blue-green / green are not the most desirable combinations for adjacent circuits. As demonstrated in Figure 17, the three red squares on the right side of the figure have more contrast with their blue background than the three light blue squares on the left, and they appear to be more visible.

Figure 17 – Lightness contrast, and red - blue color contrasts (Green, 1999)



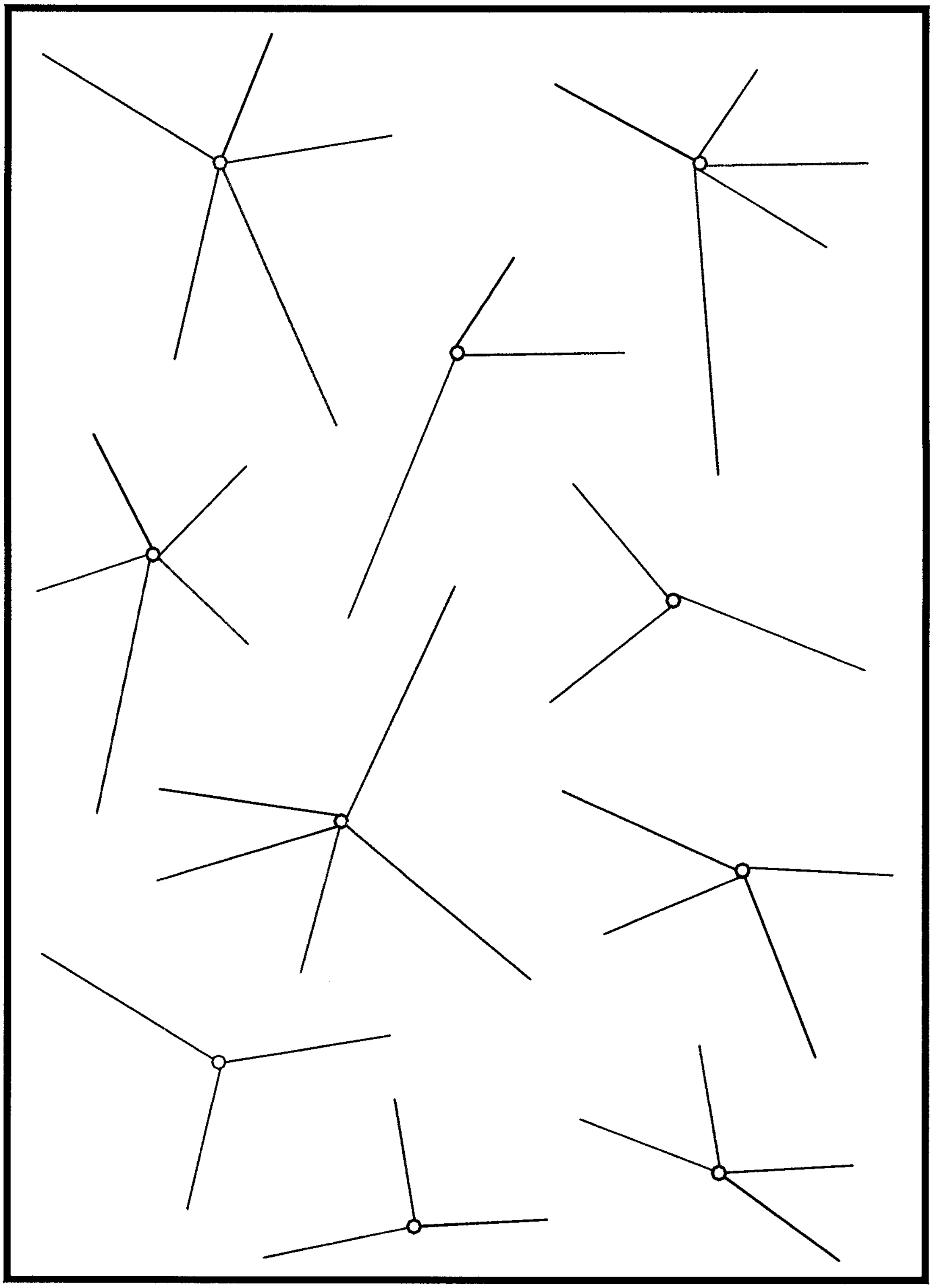
The exception is red / green combination. Although red / green are complementary colors in the color wheel, and are therefore a suitable combination for adjacent circuits, due to red / green color blindness these two colors will not be used next to each other unless they are highly saturated.

As seen in Table 4, the six most distinguishable colors can be used for circuits 20 through 25, which have the highest priority. Circuits 26 and 27 have the second highest priority. As a result, the seventh and eighth of the next distinguishable colors will be used for them. 4KV feeders 1 through 8, with priority 9 through 16, will assume the ninth color. 12KV feeders 28 and 29, with priority 17 and 18, take the 10th color. 4KV feeders 9 and 10, with priority 20 and 21, get the 11th color.

Table 4 – Feeders sorted by their priority number (Sequential, Qualitative Scheme)

PRIORITY #	FEEDER NO.	SUBSTATION ID	TOTAL	COLOR (11 Colors)
1	25	AC, AL, CO, HV, HW, MB, PB, QR	8	C01
2	24	AC, AL, CO, HV, HW, MB, PB, QR	8	C02
3	23	AC, AL, CO, HV, HW, MB, PB, QR	8	C03
4	22	AC, AL, CO, HV, HW, MB, PB, QR	8	C04
5	21	AC, AL, CO, HV, HW, MB, PB, QR	8	C05
6	20	AC, AL, CO, HV, HW, MB, PB, QR	8	C06
7	27	AL, HV, HW, QR	4	C07
8	26	AL, HV, HW, QR	4	C08
9	2	EM, HO, MB, PB	4	C09
10	1	EM, HO, HW, MB	4	C09
11	8	HO, HV, HW	3	C09
12	6	EM, HO, HV	3	C09
13	5	EM, HO, HV	3	C09
14	7	HO, HV	2	C09
15	4	EM, HO	2	C09
16	3	EM, HO	2	C09
17	29	HV	1	C10
18	28	HV	1	C10
19	11	HW	1	C11
20	10	HV	1	C11
21	9	HV	1	C11

Figure 18 – A Sequential, Qualitative Color Scheme



3.4E SUMMARY OF CIRCUIT CLASSIFICATIONS

Table 5 identifies four different classifications of circuit arrangements for coloring the circuits, each with a distinct color scheme. One of these color schemes, which is sequential and is based on feeder numbers, requires 21 colors, which is too many and therefore, not practical, as discussed earlier in this chapter. The other three classifications are recommended based on the circuit map requirements. The most widely used color scheme, the Sequential–Qualitative color scheme, which is for general use, was also used for hypothesis testing. The 11 colors selected from available colors on the City of Palo Alto GIS environment from Figure 8 are shown in Table 6. Each color in Table 6 is referred to by its pen number in the GIS environment.

Table 5 – Summary of options for feeder arrangements

OPTION	CLASSIFICATION	COLOR SCHEME	COMMENTS
1	Voltage	Qualitative, Binary	2 Colors (Red-Blue)
2	Substation	Qualitative, Regional	10 Colors From Table 6
3	Feeders	Sequential	Not Practical (21 Colors required)
4	Priority Number	Sequential-Qualitative	Recommended Model For General Use, 11 Colors From Table 6

Table 6 – Assignment of the 11 colors for the proposed color scheme

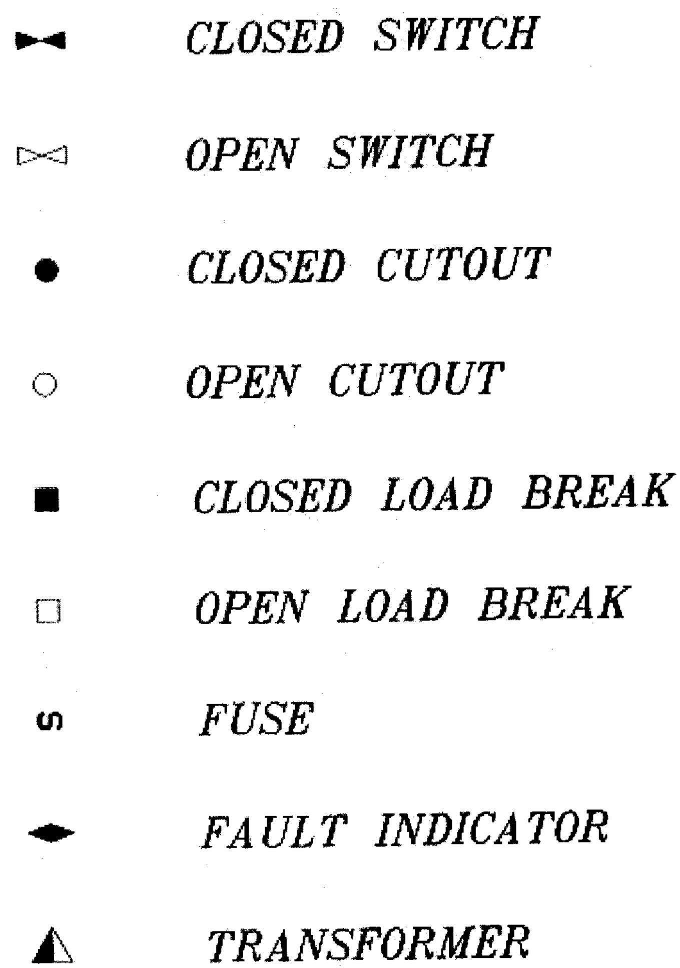
C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11
PEN 55	PEN 15	PEN 50	PEN 27	PEN 62	PEN 25	PEN 57	PEN 13	PEN 45	PEN 30	PEN 52

3.5 ALL OTHER FEATURES

This category includes all other circuit map features, such as transformers and switches which have not been included in the previous four categories (Figure 19). As discussed earlier in chapter 3 section 5, hues must be used for circuits. However, since the number of hues must be limited in circuit maps, other color qualities such as value contrast must be considered for this category.

One of the categories of contrast is value contrast, which is the contrast between light and dark, and is most visible between black and white. Black is recommended for all other features. Value contrast provides sufficient figure-to-ground relationships. According to Dent (1999), Janet Mersey labeled six (6) different color series ranging from one that displays the least order (hue-based) to one that is most ordered (value-based). The last of the series is a Black-and-White series with producing steps of gray. Often, white and black anchor the ends of the spectrum.

Figure 19 – Example of all other features



3.6 EVALUATION PROCESS

Selection of colors for a circuit map should be based on the principles of color and cartographic design. The following colors as discussed earlier, were recommended:

- Yellow or light gray for the base map.
- Shaded polygons were assigned a light, low saturated color because they are background information. In this test, they were light gray-pink.
- Black for the circuit text, and gray for the base map text.
- Several alternative color schemes for the circuits were developed and evaluated.
- All other features were black.

The effectiveness of a specific color selection can and should be tested (Brewer et al., 1997). Therefore, a pilot map test was performed on human subjects using a series of tasks and questionnaires.

The efficacy of a color-coded circuit map was evaluated by asking test subjects to perform a series of tasks on a color circuit map, and comparing performance on the color circuit map against the results of subjects performing the same tasks on a black and white circuit map. The sample was divided into two groups of 32 persons; each group performed the same task under similar conditions and within an acceptable time period. The first group worked with the color circuit map, while the second group worked with the black and white circuit map. The results from the color and the black and white map tasks were compared to validate any significant statistical difference between them.

CHAPTER 4

4.0 HYPOTHESIS TESTING AND ANALYSIS

A list of City of Palo Alto Utilities employees in the Electric Engineering, Electric Operations, Marketing, Resource Management, Telecommunications, and Water-Gas-Waster Engineering divisions was compiled. The employee list was sorted primarily by division, then by employee name, and finally a random number was assigned to each name. Every other name on the employee list was assigned a black and white circuit map, and the remaining names were assigned a color circuit map to perform the test.

All of the employees on the list were first informed about the research and then were invited to participate in the study. Those employees who agreed to participate in the study were asked to read and sign a consent form (see Appendix C) in compliance with the requirements of the Human Subjects Institutional Review Board. Subsequently, the same employees were asked to answer a demographic questionnaire (see Appendix D) about themselves in order to better categorize the test results in later analysis. The participants were then provided with a color or black and white map and a task sheet (see Appendix E). Each test subject was given five minutes to mark specific items listed on the task sheet. These items included: circuits, street names, and switches. The marked up maps were graded, and the scores were tabulated.

The map test was administered to 64 test participants, 32 for color maps and 32 for black and white maps, all affiliated with the Utilities Department, exceeding the goal of the research, which was originally about 50 persons. The breakdown of the number of test participants by division is as follows:

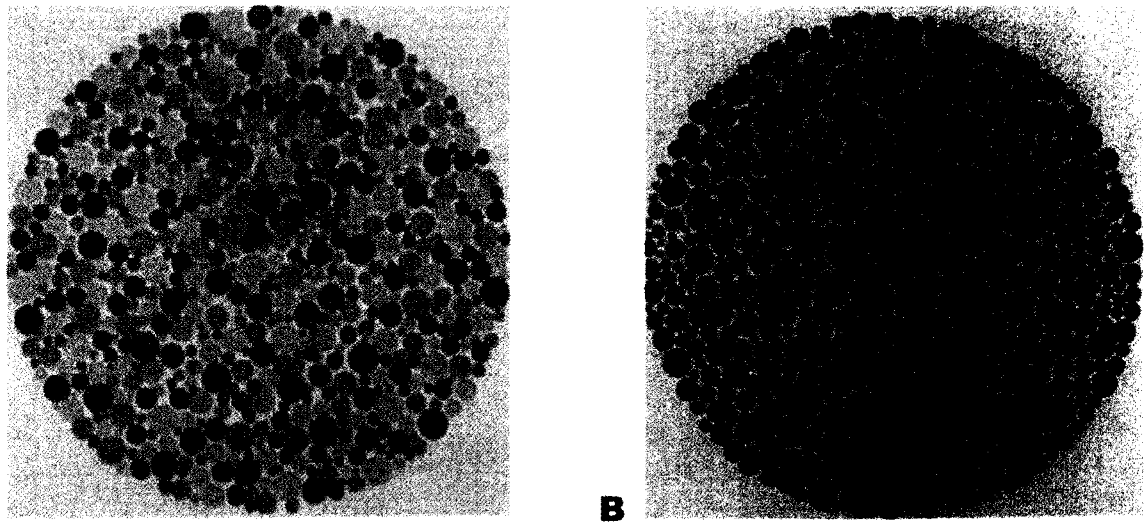
Table 7 – Participants by Division

Division	Number of Participants
Electrical Engineering	12
Electrical Operations	12
Marketing	10
Resource Management	6
Telecommunications Engineering	4
Water-Gas-Wastewater-Engineering	20
Total number of all participants	64

4.1 TEST LOGISTICS

As noted earlier, one half of the participants from each division were asked to perform the tasks on a black and white circuit map, while the other half were asked to perform the same tasks on a color circuit map. In addition, four of the test subjects, or approximately 6.25% of the test sample, who also happen to be male, were colorblind and, they too were divided equally into two groups. Two of the colorblind subjects performed the test on a black and white circuit map, while the remaining two performed the same test on a color circuit map. These four individuals who have the most common type of colorblindness, have difficulty distinguishing between green and red colors if these colors were light and not saturated. However, they did not appear to have a problem in distinguishing between green and red if these two colors were sufficiently saturated. The issue of colorblindness was a deciding factor during the selection of the circuit map colors. To test that these subjects or other participants were actually colorblind, following the completion of their demographic questionnaire, the color image test described in Figure 20, was performed (Palmer, 1999). Typically, persons with normal color vision would clearly be able to see the number 3 in A and 42 in B. Colorblind people see no number in A and 2 in B, or no number in A and 4 in B, depending on the type of their colorblindness.

Figure 20 – Colorblindness test (Palmer, 1999)



A B

A TTEST that compares the average scores of two groups of equal numbers of participants, using the equations included in Appendix G was performed. As expected, the average grade received on the color map testing was higher than the average grade received for performing the same test on the black and white map. The grade differential is significant at the .01 percent level.

To further analyze these test results, a series of comparisons based on the average grades obtained from test results on a black and white circuit map and on a color circuit map were performed by utilizing a TTEST. Using information collected from the test subjects' demographic questionnaires, the test participants were categorized in terms of their age, experience, handedness, divisions, corrective lens, gender, and colorblindness. These are major factors that affect color perceptions in map users. The results were then compared and charted in the following sections.

4.2 TEST RESULTS COMPARISON BY AGE

All test participants (in each category of color and black and white) older than the median age of the entire group of participants (45 years in both categories) were placed into one group; and the remainder, who were younger than the median age of all participants, were placed in a second group. The average scores for using black and white circuit maps and color circuit maps were compared. The results indicate that performance using a color circuit map was significantly improved compared to performance using a black and white circuit map, whether subjects were younger or older (see Table 8). Therefore, regardless of ones' age, performance on a color circuit map is superior over the performance on a black and white circuit map.

Table 8 – Age

Age	**Age > Median (45)**	**Age < Median (45)**
Average Score B&W Map	66	59
Average Score Color Map	79	81
Greater Score	Color Map	Color Map

4.3 TEST RESULTS COMPARISON BY EXPERIENCE

The subjects (in each category of color and black and white) were divided into two groups based on the number of years of work experience they had with the Utilities Department; one group consisted of personnel with more experience, and the other group of personnel with less experience. All of the subjects whose years of experience with the utility were greater than the median were placed in one group (median age was 13 years for color map subjects and 16 years for black and white map subjects); all other subjects were placed in a second group. Table 9 shows that the subjects performed better using a color circuit map than subjects using a black and white circuit map, whether the subjects belong to the bottom half of participants with fewer years of experience with the utility, or the upper half of participants with extensive experience with the utility. Although the performance on color circuit maps was significantly better than the performance on black and white circuit maps, experienced participants performed better than less experienced participants when tested on either the color or the black and white circuit maps. This may show that more experienced Utilities Department staff have more advanced map reading skills as a result of longer years of experience, compared to those with less experience. This may also be attributed to their familiarity with the circuits, which might lend to increased ease of identifying features on the circuit maps. This is more apparent with the field operations employees who are able to recite switch numbers quickly based on verbal location alone. The difference in performance between the more experienced and the less experienced staff is quite significant when using a black and white circuit map. This may show that reading black and white circuit maps is far more difficult than reading color circuit maps for less experienced staff, and that color circuit maps are essential for newer employees. The value of experience becomes apparent when comparing black and white circuit map reading to color circuit map reading. Therefore, experience counts and under equal circumstances, more experienced utility employees perform better when reading maps than less experienced utilities employees.

Table 9 – Experience

Experience	**Years of Experience > Median (13 for color, 16 for B&W)**	**Years of Experience < Median (13 for color, 16 for B&W)**
Average Score B&W Map	66	59
Average Score Color Map	80	79
Greater Score	Color Map	Color Map

4.4 TEST RESULTS COMPARISON BY HANDEDNESS

The test results were divided into two groups based on the handedness factor of the test subjects, which had been gathered from their demographic questionnaires. In each of the map tests (black and white circuit map and color circuit map tests), test results of the subjects' who are right handed were placed in one group and test results of the subjects who are left handed were placed in a second group. As shown in Table 10, whether the subjects are right handed or left handed, the performance on a color circuit map was improved over the performance on a black and white circuit map. The improved performance was more significant for right handed persons and less significant for left handed persons. This shows that irrespective of handedness, performance on a color circuit map is better than the performance on a black and white circuit map.

However, between the two groups of subjects using black and white maps or color circuit maps, right handed participants performed better than the left handed ones. This may be attributed to the fact that people who are left handed have a different search pattern for information on a map than the right handed people. Since the test had been designed by a right handed person, it may have been designed to suit the search pattern of a right handed person. This is an interesting topic for further research; however, it is not within the scope of this paper.

Table 10 – Handedness

Handedness	**Right Hand**	**Left Hand**
Average Score B&W Map	63	61
Average Score Color Map	81	76
Greater Score	Color Map	Color Map

4.5 TEST RESULTS COMPARISON BY DIVISION

The test subjects, who had been selected from six different divisions within the City of Palo Alto Utilities Department, were also divided for further analysis in terms of their respective utilities division, as shown in Table 11.

In this analysis, Table 11 shows that the performance result scores for tests on color circuit maps is greater than the performance result scores on black and white circuit maps, with the exception of result scores for tests given to subjects in the Telecommunications division. For the Telecommunications division, the result scores for tests on black and white circuit maps are greater than the performance result scores on color circuit maps. The performance difference for the telecommunications division using a black and white circuit map and a color circuit is not statistically significant. In addition, this exception can be considered an outlier and does not affect the overall results. This group of subjects has only four persons, which is not significant enough to draw any conclusive reason. The number of males and females were equal in each group; one female and one male performed the tests on a black and white circuit map and one female and one male performed the same tests on a color circuit map. None of the test subjects from telecommunications division is colorblind; however, all wear corrective lenses.

However, one of the participants from this department who was tested using a color circuit map happens to be a left handed person. As discussed earlier in handedness comparison section, this may have had an affect on the final results for this group. Overall, the left handed participants did not perform as well as those who are right handed. In addition, the two individuals who did the test on a black and white map have more work experience, which as discussed earlier, provided them with better map reading skills.

However, the overall test results were not notably affected by the test results of telecomm division and performance on color circuit maps was significantly greater than the performance on black and white circuit maps in the utilities department.

Table 11 – Division

Division	**Electric Engineering**	**Electric Operations**	**WGW Engineering**	**Telecomm**	**Resource Management**	**Marketing**
Average Score B&W Map	72	71	52	63	67	58
Average Score Color Map	94	88	74	58	86	70
Greater Score	Color Map	Color Map	Color Map	Black and White Map	Color Map	Color Map

4.6 TEST RESULTS COMPARISON BY CORRECTIVE LENS

Test results collected from the participants were also categorized based on a corrective lens factor. In other words, for both categories of color maps and black and white circuit maps, all participants who wear corrective lenses were placed in one group and the ones who do not wear corrective lenses were placed in a second group. The average scores of the map testing performance of both groups were compared. Table 12, shows that the performance scores in both categories are greater when using color maps. Therefore, it does not affect the results whether the subjects are using corrective lenses or not. Performance was significantly better when test subjects used color maps.

Table 12 – Corrective Lens

Vision	Corrective Lens	No Corrective Lens
Average Score B&W Map	64	58
Average Score Color Map	77	88
Greater Score	Color Map	Color Map

4.7 TEST RESULTS COMPARISON BY GENDER

In addition to the preceding categories, the test subjects were also divided by their gender. Table 13, shows that in both test categories, the subjects were divided by their gender. When the average scores for using a black and white map and a color map were compared, both male and female test subjects' performance improved significantly when a color circuit map was used. This shows that regardless of the subjects' gender, the subjects' performance on a color map is improved as opposed to using a black and white circuit map. In both categories the male subjects performed better than the female subjects; however, the difference is not significant. This may be another topic for further research, which is beyond the scope of this paper.

Table 13 – Gender

Gender	Female	Male
Average Score B&W Map	62	63
Average Score Color Map	74	83
Greater Score	Color Map	Color Map

4.8 TEST RESULTS COMPARISON BY COLORBLINDNESS

The test subjects were also divided by the colorblindness factor obtained from their demographic questionnaires. In each category of black and white circuit maps and color circuit maps, all those who are colorblind were placed in one group, and those who are not colorblind in a second group. As seen in Table 14, it does not matter whether the subjects were colorblind or not. The performance on a color circuit map was better than the performance on a black and white circuit map. This shows that irrespective of colorblindness, performance on a color map is better than the performance on a black and white map. However, the difference in performance for normal color vision was quite significant and not so significant for colorblind subjects.

Table 14 – Colorblind

Color vision	Colorblind	Normal Color Vision
Average Score B&W Map	79	61
Average Score Color Map	83	80
Greater Score	Color Map	Color Map

4.9 SUMMARY OF TEST RESULT COMPARISONS

In summary, as shown in the comparison tables, the results were broken down into 18 different categories for further analysis based on the data gathered from the questionnaires. In every category the average score of performance was greater when subjects used color maps instead of black and white circuit maps, with the exception in the telecomm group test results, which was discussed earlier. However, the overall results of performance on color circuit maps is so much greater than the performance on black and white circuit maps that this outlier did not skew the test result.

The results prove, with a great certainty (greater than what the researcher had anticipated), that the difference between performance using a black and white circuit map and performance using a color circuit map is very significant. Performance is significantly improved when a color circuit map is used instead of a black and white circuit map. Therefore, this test validates the hypothesis of superiority of color over black and white when looking at an electric circuit map.

However, this hypothesis does not state that "any" color circuit map is superior to "any" black and white circuit map. The research started with an excellent circuit map and considerable effort was dedicated to designing the circuit map, its symbols, sizes, scales, shapes, fonts and other circuit map elements. On such a map, using knowledge gained from research, experience, feed back, and testing on color, a set of colors was chosen for the prototype map for testing. Such a color circuit map was tested against a black and white circuit map. Therefore, when speaking of superiority of color circuit maps over black and white circuit maps, the assumption is that the colors are chosen carefully, based on knowledge, experience, and concepts of color described throughout this paper. Under such conditions, a color circuit map is superior to a black and white circuit map.

The main difference between a black and white circuit map and a color circuit map is the coloring of the individual circuits. The base map and shaded polygon colors were very light with low saturation, while all the other features remained black in both maps to limit the number of colors used. In addition, both base map and circuits were line features. The only color element that is not a line feature was the shaded polygon. Obviously the test results prove with great certainty the superiority of a color circuit map over a simple black and white circuit map. This conclusion supports the proposal that all the map color concepts discussed throughout this paper which were considered when selecting colors for the features of circuit map are relevant in a circuit map environment where the primary functional elements are circuits, which are line features.

CHAPTER 5

5.0 CONCLUSION

By exploring available scientific literature, hypothesis testing, and statistical methods as well as confirmation based upon personal experience, this research demonstrates that a color circuit map is superior to a black and white circuit map. This research validates the hypothesis of superiority of color over black and white on an electric circuit map. This superiority could possibly be expanded to all other types of maps, since color maps have been shown to allow for more accurate communication of information and have been found to be more pleasing and effective for the map users.

In addition, this research suggests that the extra time, effort, and cost required to produce high quality color maps is justified. However, knowledge of available guidelines about color use should be carefully considered so that, as described in chapters 1 and 4, inferior color maps with poorly chosen colors are not the end result. Therefore, when referencing color maps, the assumption is that a considerable amount of thought and effort has been dedicated to the colors chosen for the map, based on available literature on color use in cartography. Some of these guidelines and color concepts that are directly related to the electric circuit map are discussed in this paper.

APPENDICES

APPENDIX A – APPROVAL LETTER SJSU

San José State
UNIVERSITY

Office of the Academic Vice President

Associate Vice President Graduate Studies and Research

One Washington Square
San Jose, CA [illegible]
Voice: [illegible]
Fax: 408-924-2477
E-mail: [illegible]
http://www.sjsu.edu

To: Medhi Jamshidipour
1760 Halford Avenue, #370
Santa Clara, CA 95051

From: Nabil Ibrahim,
AVP, Graduate Studies & Research

Date: November 27, 2001

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Color vs. Black & White Circuit Map."

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Nabil Ibrahim, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subjects portion of your project is in effect for one year, and data collection beyond November 26, 2002 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

APPENDIX B – APPROVAL LETTER CITY OF PALO ALTO

City of Palo Alto
Utilities Department

To whom it may concern:

This is to confirm that Mehdi Jamshidipour, utility engineering estimator for City of Palo Alto Utilities, and a graduate student at San Jose State University, Department of Geography is allowed to test his hypothesis of superiority of a color electric circuit map over a black & white electric circuit map.

He agrees to present a copy of his Master's Thesis to the utilities department when it is completed.

Patrick Valath, P.E.

Patrick E. Valath 10/9/01

Senior Electrical Project Engineer

Utilities Department

Divisions

Administration
Director's Office
650.329.2277
650.321.0651 fax

Administrative Services
650.329.2148
650.321.0651 fax
Customer Service Center
650.329.2161
650.617.3142 fax
Credit and Collection
650.329.2333
650.617.3142 fax
Computer Services
650.329.2148
650.321.0651 fax
Utility Marketing Services
650.329.2241
650.617.3140 fax
Public Relations
650.329.2656
650.326.1507 fax

Engineering
Electric
650.566.4500
650.566.4536 fax
Water-Gas-Wastewater
650.566.4501
650.566.4536 fax
Telecommunications
650.329.2275
650.326.1507 fax

Resource Management
Supply Resources
650.329.2689
650.326.1507 fax
Competitive Assessment
650.329.2595
650.617.3140 fax

Operations
Electric
650.496.6934
650.493.8427 fax
Water-Gas-Wastewater
650.496.6982
650.496.6924 fax

P.O.Box 10250
Palo Alto, CA 94303

APPENDIX C – CONSENT FORM

Responsible Investigator: Mehdi Jamshidipour
Title of Protocol: Color versus Black & White Electric Circuit Map
Agreement to Participate in Research:

1. I ________________________________ have been asked to participate in a research study investigating

   (Please Print Name)

   superiority of color over black & white electric circuit map conducted by Mehdi Jamshidipour, graduate student in the Department of Geography & Environmental Studies, College of Social Sciences, San Jose State University.

2. I have been asked to highlight with a marker, in the test map provided to me by the researcher, the circuits, streets, and switches requested in the questionnaire. I will participate in (please circle one):

   a. City of Palo Alto, civic center, December 2001
   b. City of Palo Alto, Municipal Service Center, December 2001
   c. City of Palo Alto, Elwell Ct. office, December 2001

3. I understand that there may be some slight eyestrain from undertaking this test; otherwise, there are no other risks anticipated.

4. I understand there may be some benefit such that I will have an understanding of how well I can perform tasks on a circuit map.

5. I understand that the results of this study may be published but no information that could identify me will be included.

6. I understand that I will not receive any compensation for my participation in this study.

7. I understand that if I have any questions about the research, I am to contact Mehdi Jamshidipour, (408) 241-3758. If I have any complaints about the research, I can direct them to Dr. David Helgren, Geography Department chair, (408) 924-5475. If I have any questions or complaints about subjects' rights or research-related injury, I can direct them to Serena Stanford, Ph.D., Associate Academic Vice President for Graduate Studies and Research, (408) 924-2480.

8. I understand that no service of any kind, to which I am otherwise entitled, will be lost or jeopardized if I choose not to participate in this study.

9. I consent to participate in this study voluntarily without undue influence or coercion by other persons. I understand that I am free to withdraw anytime without prejudice to my relations with San Jose State University or any other institution.

10. I understand I will receive a signed and dated copy of this consent form before I begin the test.

- **The signature of the subject on this document indicates agreement to participate in this study.**
- **The signature of the researcher on this document indicates agreement to include the below named subject. The subject has been fully informed of his or her rights.**

________________________________ ________________________

Subject's Signature Today's Date

________________________________ ________________________

Investigator's Signature Today's Date

APPENDIX D – DEMOGRAPHICS QUESTIONNAIRE

QUESTIONNAIRE (Subject # xx)

1. (Optional) First Initial, Last Initial,: ______________

2. Age (Circle nearest number):

20 25 30 35 40 45 50 55 60 65

3. Department: ______________ 4. Division______________

5. Years of experience with utilities:

6. Gender: M F 7. Handedness: R L

8. Do you wear corrective lenses? (Circle one): Y N

9. If you answered "no" to 8, then please continue to 10; otherwise, please circle what applies to you:

a. Nearsighted b. Farsighted c. Astigmatism d. Other

10. Are you color blind? Y N

11. If you answered "yes" to 10, please explain.

12. What type of maps do you use? Please circle what applies to you:

a. I do not use maps

b. Street and locator maps

c. Navigational and/or aeronautical charts

d. Electric distribution, communication, & circuit maps

e. Water, Gas, Wastewater maps

e. Thematic maps— engineering, geological, meteorological, etc.

f. Other; Please specify: ______________________________________

APPENDIX E – TASK SHEET QUESTIONS

TASK SHEET

Please perform the following task in their numerical order on the attached portion of city of Palo Alto's electric utility circuit map.

Use a marker and trace all the switches and circuits.

1. Highlight University Avenue.
2. Highlight switch 1819X.
3. Highlight the circuit between switch 1930X and 1932X.
4. Highlight the circuit AL-20 starting from AL Substation towards switch 2018X.
5. Highlight the circuit from switch 1921X towards switch (cut out) 889.
6. Highlight the circuit AL-20 between switch 2019X and switch 2018X.
7. Highlight the circuit from switch 1965X towards switch 1967X.
8. Highlight the circuit between switch 1810X and switch 1810Y.
9. Highlight switch (cutout) 905.
10. Highlight the circuit from switch 1929X towards switch 1967X.
11. Highlight Scott Street.
12. Highlight the circuit between switch 1921X and switch 1923X.

APPENDIX F – LETTER OF APPRECIATION

Monday, January 14, 2002

My Dear Colleagues,

I would like to express my appreciation for your participation in my research. The research is ongoing, even though the hypothesis-testing phase of it is completed. Due to your participation and our Electrical Engineering management support, I have gathered enough data to start analyzing and drawing conclusions from the data collected. Once the entire research project is completed, a copy of it will be available in the bookshelves outside my office at Elwell CT. If you have any questions, please feel free to call me at (650) 566-4531.

Yours truly,

Mehdi Jamshidipour

cc: Tomm Marshall, PE, Electrical Engineering Manager

Patrick Valath, PE, Senior Electrical Project Engineer

Human Subjects Institutional Review Board, SJSU

APPENDIX G – STATISTICAL METHODS

TTEST Method (McGrew, Chapman, & Monroe, 2000)**:**

H0: $\mu 1 = \mu 2$

Null hypothesis states that there is no difference in performance between using a color circuit map and using a black and white circuit map.

HA: $\mu 1 < \mu 2$

Alternate hypothesis states that there is a significant difference between a color circuit map and a black and white circuit map. Performance on a color circuit map is significantly better than on a black and white circuit map.

$\alpha = .05$

Is the significant level that is generally used and accepted by statisticians.

$n_1 = 32$

Number of test subjects from the City of Palo Alto's Utilities department for black and white maps.

$n_2 = 32$

Number of test subjects from the City of Palo Alto's Utilities department for color maps.

$df = n_1 + n_2 - 2$

Degrees of freedom would be $(32 + 32 - 2) = 62$

t = 1.645

Is the critical value from t table for the .05 significant level, one-tail ttest 62 degrees of freedom.

TTest

One tail (since the assumption is that there is improvement in performance with color map), difference between 2 sample means will be conducted.

$$t = (\mu_2 - \mu_1) \;/\; (\sigma_{\mu 2 - \mu 1})$$

$$\sigma_{\mu 2 - \mu 1} = \sqrt{\sigma_2^2 / n_2 + \sigma_1^2 / n_1}$$

Score will refer to the number of correct answers by test subjects while performing the tasks on the maps. It should therefore be less for the black and white circuit map, in order to reject the null hypothesis. The calculated t (3.88) must be greater than the critical t value of 1.645 in order to reject the null hypothesis.

μ_1

Mean score (62.37) of performance on a black and white circuit map.

μ_2

Mean score (79.95) of performance on a color circuit map.

$\sigma_{\mu 2 - \mu 1}$

Standard error (4.53) of the difference of means of the two performances.

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